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EXPERIMENTAL RESEARCHES
INTO THE PROPERTIES AND MOTIONS OF
FLUIDS.

WITH THEORETICAL DEDUCTIONS THEREFROM.

BY

WM. FORD STANLEY.

1881.

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NEW-YORK.

PREFACE.

ALTHOUGH I feel personal prefaces are objectionable, I think it due to those who may follow me in this treatise to point out certain limits of my knowledge of the subject treated. I will therefore briefly state the circumstances under which it was written. Earlier than the past five years I had no intention of specially studying the subject, and had certainly no idea of writing upon it. I had previously to this period taken for the amusement of my leisure an experimental examination of the undulatory theory of light, which I could not satisfactorily comprehend. In following up my experiments for two years I found my eyesight impaired, and was advised that it would be necessary to leave these experiments, and also close application to reading, for some years, which I did very reluctantly. One branch of experiment, somewhat relative to my former studies, however, appeared open to me. The theory of undulation of light was generally introduced to our conception by philosophers by similitudes of the motions of water-waves and sound-waves; I thought I would investigate experimentally, as far as possible to me, to be assured our conceptions of these motions were real, upon inductive principles, similar to those I had been employing for investigation of light. In this subject, taking no preconceived theory whatever for my experiments, I soon became absorbed in observations of the motive effects evident in the directions taken by impressed forces in fluids under various conditions of resistance; wherein it appeared to me quite evident that there was yet an immense amount of work to be done in researches in the motions of fluids, before theoretical principles of the sciences of hydrodynamics and acoustics could be fixed upon mechanical ciples with any great precision. It was therefore clear to me n this direction I might, if I had the ability, enter upon fields ch quite as new as in my former studies.

ommencement of my work, looking as briefly as I could

rks of others in search of purely mechanical ideas, it
me that in science with respect to fluids, as in the earlier
ome sciences which have become in our time exact, as
onomy and chemistry, too great reliance had been placed
ingenious theoretical idea which was not clearly and
upported by direct observations or by experiment, there-
rily only brought to bear on facts by the introduction
arbitrary functions; whereas too little dependence had
upon *purely* inductive methods. Thus, to take an in-
philosophy of wave motions, it was in the first place
wind naturally produces waves upon water, as we find
the surface of the ocean. Then from such knowledge it
r to be most logical for researches into the principles of
s, to investigate the action of the wind upon a liquid sur-
is case, if we obtained a clear perception of the principles
, by finding causes sufficient to *produce waves*, it would
e clear that the same mode of action would *maintain*
en produced; and that with this knowledge, if we could
o far as the production and maintenance of waves were
ur ideas would be fairly *complete.* We might then, as
consideration to this investigate the constant action of

motions at all times, although most evidently in the dissipation of impressed forces to equilibrium upon the open liquid surface.

For the work before us, wherein I hope some of my ideas may be accepted, these I anticipate of very different values. Thus, the first three chapters are speculative, and even in parts hypothetical; they are generally attempts to apply mechanical principles to hydrostatics, and needed on some points much more leisure than I could command. The first chapter I felt necessary, to offer some theory of the fluid condition that appeared to me consistent with our acquired knowledge of matter and with my experiments, particularly to account for the rigidity and yet mobility of liquid systems. In the second chapter on liquid surfaces I have ventured to differ from the generally accepted theory of *tensile* surface for liquids, founded on the researches of many great philosophers, from Segner (1751) to Clerk Maxwell. My experiments have led me to take quite the opposite view, namely, that such surfaces are *extensile* instead of tensile; except for free films, which are clearly *tensile* by the position of the attractive matter which composes them. This subject I think I may have insufficiently worked out, although my experiments in this, as in most other subjects taken, are ten times the number given. In the third chapter some propositions are offered which will, I am sure, need partial correction. In the fourth chapter and onwards I think my work is more important, and this may be taken quite separately from earlier more speculative parts. The theory I develope of rolling contact of fluids moving upon static bodies will possibly be established by any amount of further research. With this, I believe quite original work, I have taken as great care as I was capable of. In the fifth and sixth chapters I offer principles of conic resistance in fluids which give simple mechanical laws for the class of motions sometimes defined as vortices, eddies, and cyclones. These mechanical laws may be ultimately shown to be general, if not the universal principles, upon which all fluids move by displacement upon themselves; which will open out new theories of fluid motion. The eighth chapter, on resistance of solids, is very incomplete on certain points for want of sufficient research into the works of others and more experiment; therefore it may be considered to be in a certain degree speculative. The ninth chapter, on diffusion of fluid forces, I believe to be important, although it may need more experimental demonstrations than I have given.

In the Second Section, devoted to the discussion of cosmical phenomena in fluids, I have in some parts of this work followed certain ideas proposed by Lenz, Herschel and Dr. Carpenter. By further introducing principles of motions in fluids that I have discovered, I am able to propose certain universal systems of motion for fluids upon the globe; consistent with the distribution of land and water as it exists, and at the same time such as will constantly influence this distribution. I have some hope that these researches may aid in the elevation of the sciences of physical geography and meteorology, now sciences of *observation*, to sciences of *principle*, to rank at some future period with such exact sciences as astronomy and chemistry, and that the principles proposed may be of some value also to systematic geology. I have no doubt, however, that my propositions will need much future correction to adapt them to local circumstances, and altogether, I consider my efforts only the commencement of systematic work in this field of research.

For the Third Section, on Waves, after making many experiments, I found my experimental inferences agree most nearly with ideas first published by M. Flaugergues in the *Journal des Sçavans*, 1789. His principal experiment is, however, very rough, namely, the striking of a liquid surface with a copper rod to generate waves. But his separation of the functions of protuberances and hollows appears to me most rational to observation. Following these ideas, and endeavouring to refine the like experiments, I fell into a track which had already been traversed without my knowledge by the important experiments of Mr. J. Scott Russell, of which I had found no reference in any work on hydrodynamics or physics that previously came to my hands. But as I was working for the demonstration of principles only, I do not regret the want of this knowledge at first, for if I had possessed it at the time it would have materially curtailed the interest I took in my experiments, by which alone I have attempted to study principles throughout this work, and my opinions of wave phenomena, whatever they may be worth, would have been less original. I have, however, replaced

Mr. Russell's work for my own where it appeared more demonstrative.

I have written a Fourth Section that is really necessary to complete my work—*upon sound motions in fluids;* which is withheld from publication, references to which are now unavoidably mixed with this matter. This part was written in continuation of wave motions. I think it may perhaps be an important part, having devoted much time to it, but I commenced it first, and completed it before the important inventions of Telephones by Prof. A. Bell, and its congeners the Phonographs and Microphones were discovered, which instruments I have not had much time to consider, but think they will under experiment materially assist me in demonstration of the principles introduced. I therefore defer the matter of sound motions in fluids for a year or two to repeat my experiments. Some of the propositions of the first chapter were specially written in reference to sound motions, as in the theory adopted I thought it necessary to assume a condition of *quiescent equilibrium* for fluid molecules to demonstrate the action of compound sounds. This would possibly not have been necessary for the proposition here given of the ordinary motions of fluids. Further, in omitting the fourth section, I was compelled to withhold a proposition relative to conditions of *static* in comparison with *motive* equilibrium of molecular motions in fluids, in the first chapter, which would have been incomprehensible without further development in the fourth section on sound; I feel this withdrawal leaves the first chapter, now condensed from what was formerly two chapters, in a certain degree abrupt and incomplete.

My work is thrown into *propositions,* which is perhaps a rather pompous style for such a work, but I mean by these only some things *proposed.* I adopted this system as it appeared to give me liberty to offer speculative ideas freely, and at the same me to keep them in more concrete form, which was necessary for h intermittent work as I was able to carry on when leisure tted. I intended at first to use these propositions, which rely, *notes made in presence of my experiments,* only as a g to erect my ideas, intending to remove this entirely completed my book, supplying its place by some more modern form of writing, but I found this would be more difficult and tedious than anticipated, so that I now leave it in its rough state, and must therefore depend for my readers on the smaller number who look at *things* rather than *forms*. Further, I have not for the same reasons attempted quantitative or numerical deductions, except in a few cases, as I am sure this may be done better when my ideas are proved or disproved, as it would also be better done by others who possess superior educational advantages over myself. Altogether I propose my work as a primitive sketch of the subject from which I anticipate, perhaps vainly, that more perfect work may be reared at a future time by some highly educated mathematician who may care to follow me, and clothe with his skill the rude, although I believe natural, underlying forms that I have brought in some cases to light.

I hoped, when my work was complete in its present form, to have obtained the assistance of some well read, or well instructed student to edit it for me, but after a great amount of correspondence, failing in this, I endeavoured to get my proofs read from press by some eminent men to whom I thought the originality of my researches might be of sufficient interest. In this matter I partially succeeded, and am greatly indebted for valuable occasional critical notes to the kindness of Prof. F. Fuller, who read my first proofs of chapters I. to VII. inclusive, also chapter X. I am also indebted to Prof. Stokes, who only gave me a very conditional promise of help at commencement, for valuable critical notes on parts of chapters I. and III. If I could have obtained a little more assistance of this kind, there is no doubt my work would have been of much greater interest, and I could have avoided many faults. I am also indebted to Prof. Hay for some logical and grammatical notes, and for assistance with the index.

South Norwood, Aug. 1881.

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EXPERIMENTAL RESEARCHES
IN THE
PROPERTIES AND MOTIONS OF FLUIDS,
AND
THEORETICAL DEDUCTIONS THEREFROM.

SECTION I.

THEORETICAL CONDITIONS OF THE FLUID STATE AND MOTIVE PROPERTIES OF FORCES IN FLUIDS.

CHAPTER I.

PROPERTIES OF THE FLUID STATE OF MATTER.

1. Introduction.—*a.* Sir John Herschel tells us that "If there be one part of dynamic science more abstruse and unapproachable than another, it is the doctrine of propagation of motion in fluids, and especially in elastic fluids like the air, even where the amount and application of the original acting forces are known and calculable." This was written at a time when contemporary science regarded fluid as inert matter which moved only as it was moved by exterior forces, so that the directions and values of these forces only were to be considered as active upon *mobile matter in perfect equilibrium.* By our modern dynamic theories of fluids we assume that the molecule of a fluid is *active*, and is never at rest in a state of equilibrium. Therefore the difficulty of research in motive forces in fluids under the impression of exterior forces becomes almost infinitely greater, as we have now not only to consider movements by the impression of forces upon the molecule in a position of equilibrium; but we have to consider its movements in composition with er motions that exist already within its highly motive matter; and ugh there may be a general equation of the sum of these move- any system of motion assumed to progress from molecule to only will be irregular both in its velocity and in its course.

These difficulties appear to me to be so great that I cannot pretend to any powers to meet them. I therefore feel bound to follow the track of all writers upon acoustics, hydrodynamics, and chemistry in considering the atoms or molecules of fluid matter to be by some cause in a state of sensitive equilibrium, and motive only so far as experiment alone indicates; at the same time it must impress every thoughtful man who follows the evidences of his times that there exists a perfect continuity of equivalence for the conservation of all forces, although these admit only of observation under special motive forms. This I believe was first ably pointed out by Sir W. Grove in his *Correlation of Physical Forces;* but it is further developed almost to a certainty by the careful researches of Dr. Joule for possibly the most difficult case of correlation, namely, that between mechanical forces and the action of heat. It nevertheless does not appear in this last case, any more than in others, equally certain that such forms of impression of force as we may produce mechanically shall be reproduced by like forms as heat; for in this, mechanical forces themselves may be converted into other forms, as, for instance, the direct impulse of the clapper of a bell produces in the bell vibration, and in the air sound motion; further, we have no possible evidence of any molecular motion whatever, so that we may have by equivalence of energy a dynamic unit represented by any force, as by a pressure, a vibration, a free trajectory, or otherwise.

b. The diffusion and pressure of gases by assumed locomotive or trajectory forces in free molecules, founded on theories of Clausius and Clark Maxwell, present to the mind a very cogent theory for the action of heat in these bodies. But the existence or presence of such free motions appears to my mind to entail immense difficulties for the relative consideration of other forces, as, for instance, in our most exact science of chemistry, where the motions of atoms become, if anywhere, most evident, and the atoms of matter in combination and dissociation appear, as far as outward evidence is concerned, either to approach or to recede *once* only; the same observation will apply to forces of cohesion and of diffusion. It appears also that a state of equilibrium for every particle is required by our theories of the motion of sound in air, where the molecular equilibrium is generally assumed to be perfect and highly sensitive, as in Lord Rayleigh's important work; or for such experimental cases as those considered by M. Plateau in his eminent work, *Statique expérimentale et théorétique des Liquids soumis aux seules forces molé-*

culaires, for capillary and other conditions of assumed equilibrium. There is no doubt that under the condition of perfect equilibrium, a particle would be motive by the constant active presence of exterior forces; but as these forces would be exterior only, they would be subject to general laws of impression only.

c. Upon the above conditions it appears to me that some of the difficulties of conception of a possible sensitive equilibrium of the molecule, as it appears experimentally to exist in fluid matter, may be met in that the same value of the dynamic unit of forces may be found either in *any* form of motion or in the static conservation of its force. This last has been compared to the conservation of energy in bent springs, which has been applied to cases wherein active forces appear to be lost, as where heat forces become latent. Such cases, it appears to me, may be realized by assuming certain physical conditions in the *construction* (if I may so term it) of the atom or smallest part of matter. For this I shall offer some ideas, partly only original, to support the conditions of energy and of equilibrium of the particle, as it is established by the doctrine of position relative to attractive forces, or of *potential energy*, wherein a particle raised or pressed to a static position by a force that acts inversely to, and exceeds its attraction to other matter, may cause the particle to rest in or about this new *static* position, from which it may react at another time with force equal to that employed in its original elevation or pressure. This matter I find most clearly and ably discussed by Dr. Balfour Stewart in his work on *Elementary Physics*, §§ 100, 240, &c.; however, I shall confine these speculative matters entirely to the first chapter, as I take my hypothetical ideas of molecular forces in fluids to be quite secondary to the purposes of this work; I will also endeavour to treat this part of my subject in all cases as briefly as possible.

2. **Fluidity of Bodies.**—*a.* Perhaps the most simple definition of *fluidity* would be that derived from the Latin, for which we may take *fluens* or *fluidus*, which words will particularly indicate the terial property in a body of *flowing*. Taking this definition, and ceiving a fluid body to be alike in all its parts, and that these are coherent to each other, which appears physically to be the tion of all conceivable matter, we may then clearly define a fluid *eneous matter that can flow in continuous mass.*

his manner we take the fluidity of a body to be its physi- of flowing simply as here proposed, which will be in every way convenient for this treatise, then this property of fluidity will be a *relative quality*, dependent upon the facility with which the constitution of the body permits it to *flow* from any cause, that body being considered to be the *most fluid* that can flow under the impression of the *smallest amount of applied force.* Under this condition, if we make no special definition of the mode in which the force is to be applied, we may include in our considerations all forces possible to affect the flowing or fluidity of the body. Therefore these forces may be interior or intermolecular, or be applied exteriorly, as, for instance, the force that produces the fluidity of a body may be generated by intermolecular repulsion by heat, or by electricity, if such forces cause molecular repulsion, as they appear to do, or by molecular vibration, as supposed by some, or percussion and recoil of free trajectories, if it is possible that molecules can possess such forces in continuity. The fluidity may otherwise appear as an effect of exterior forces, as by the action of gravitation pulling the molecules in mass systems to a level surface, thereby inducing equal gravitation; or by pressures, as in the coining of metals, in which case otherwise rigid solid bodies *flow* into the interstices of a mould. Under the impression of *extreme* external pressures every form of matter might be demonstrated to possess some small functions of fluidity or of flowing, the quality here defined.

c. Taking the above conception of fluidity, it becomes evident that when we endeavour to define the exact limits of flowing quality which we may think to be sufficient to qualify a body as a *fluid*, there will appear at once to be a difficulty in defining the exact amount of the *flowing* quality in which this definite form of matter should be considered to commence. This we may conceive, in that it would not be an extremely difficult task taking all known bodies, simple and compound, to arrange them in a long consecutive series upon the principles here given of the flowing quality alone, that the series might extend proportionally to the fluidity each material possessed from the most attenuated gas to the densest solid at some temperature taken. To follow the conditions of this idea we might take, for argument sake, the fluidity of bodies that we might imagine would rest at the extreme ends of such a relative series; say, for instance, a Sprengel pump vacuum off hydrogen for the most fluid end, and steel for the opposite most solid body in which we could trace elements of fluidity. The part of such a series where a body could *just flow* to a level surface under the action of gravitation upon its parts might be possibly near the centre; we will assume that in this centre the mean proportional body may be represented by treacle. Then, in this case, for the definition of a fluid we might conceive of the whole series we have arranged, that on one side of this central line all bodies would be solids, and on the other all fluids. In this case we should certainly find that when we came more particularly to examine the division we had made, that on either side of our selected line we should have bodies that differ very little from the one we have taken, say, for instance, in this case that we have next the treacle, towards the solid end of our series, a mass of the kind of resinous turpentine that exudes from the spruce fir, and on the fluid side some mountain honey. By taking these instances it is very clear the line we have chosen is in no way marked for its special fluid qualities from other matter. If we had taken a point much higher in our series, say copper, which will *flow* readily in all the interstices of a die, under the pressure of a coining press, as a perfect liquid would by gravitation simply, in this case we might have in our series, towards the solid end, say brass, which would *flow* less easily, and on the fluid side, say pewter, that would flow more easily into the die under pressure. It will be easily conceived that the same proportional quality of fluidity might occur in any other part of our series that we might select for the division of bodies, fluid from solid.

d. For another instance of the fluid properties of bodies we may take the action of the separating force heat, evidently the most general cause of fluidity. This we find expands most bodies in approximately equal ratio to the temperature over a certain wide range, the fluidity increasing in some cases proportionally to the expansion. Take for instance glass. This when cold forms a dense homogeneous mass, but as we apply heat after a certain point it passes gradually through all the degrees of visible fluidity until it ppears as a limpid liquid, without any definite point of change from solid to the fluid state.

The value of these considerations is, that fluidity may be taken to very general physical property of matter in *some degree*, and this ut to us a road to experiment in some instances, wherein we y inferences from the properties of motion in homogeneous e such motions can be followed that may be applied in fluids, bearing always in mind that it is the relative rty only of these bodies that we follow. This principle ken advantage of in this treatise for a few experi-

return to our imaginary proportional series of bodies from the most mobile fluid to a dense solid, perhaps the ct line that could anywhere be drawn would be between l gases, as the gas appears to assume very generally a that of power of *unlimited attenuation.* But in this the experiments of Andrews and other experimenters point hat the distinction is more apparent than real, and that under experiment liquids and gases have more pro- ommon than the most easily defined liquids and solids servations.

comes most reasonable to consider upon the above as is generally assumed to be the case, that the perfect idity does not exist in any material body; all fluids d to be in different degrees cohesive, viscid, plastic, and ssessing internal construction of parts, or chemical ar- which do not admit of a perfect mobility of the rts which would be necessary for the condition of perfect his must naturally be the case, as it does not appear ceive the possibility of the existence of a mass united by

Apparent Physical Homogeneity of Fluid Matter.

3. PROPOSITION: *That a fluid is to impressed forces* ***physically a*** *homogeneous system of matter. That it is composed of* ***separate units,*** *whose forces, attractive, repulsive, or otherwise motive,* ***are equal in*** *each unit, and that in this equality consists the apparent* ***homogeneity.***

a. By assuming perfect equality of dimensions in particles of a fluid, and of each particle possessing equal forces in any system composed of many such particles, the separate particle being free from excess of attraction, so that it may rest in a state of sensitive *unstable* equilibrium with all external forces; then a pressure upon one side of the particle cannot exceed that of the sum of the pressures upon the opposite side without the particle moving towards the minus pressure. A mass composed of such sensitive particles would be a fluid. In the above case it is not necessary to assume the particle as the smallest quantity of matter. It may be such a quantity or a larger quantity, provided the state of equilibrium is perfect.

b. It does not appear that the same sensitiveness of equilibrium will apply to the position of any particle in contact with a solid or another fluid, as the surface of the other matter may possess a system of attractive or repulsive forces that does not *conspire to equilibrium* at contact with the first, so that the equilibrium at the meeting of distinct systems will be less easily defined, as I will hereafter show, than the above.

c. By the above conditions we may assume that a fluid system by the equality of forces about the particles will produce a homogeneous whole, so that any force that has sufficient power to break or disturb the physical construction of one portion of the fluid mass will also have equal power over any other portion. Therefore friction of resistance to a moving body in the fluid will be simply in the ratios to functions of cohesion of the nearest particles of the mass of the fluid to the moving body, and not as a function of the weights of matter superimposed, or pressing about or above the moving dy that is resisted. For in the construction of a fluid, if we were imagine it as a simple aggregation or admixture of equal detached te particles of loose free mobile matter, however small, not arranged upon a plan capable of producing perfectly homoquilibrium, or of equal *smoothness* in the mass, it would be t in direct ratio the particles might be jambed to-

eld down by the weight of others above; each particle
rate identity, they would interlock, and the resistance
n of force within the fluid would increase. This would
nably the case with separate particles of every form of
under the action of gravitation or of pressure, whether
division. For instance, powdered chalk may be com-
very resistant solid; or if we were to take a pile of
ers the friction of moving laterally one of the lower
be nearly as the weights of the sheets above it. It
lt to be assured that entirely different conditions to
ld with every possible fluid.

possibly under the influence of a theory prevalent in
nth century—that a fluid was a mass of detached par-
sentable by a mass of fine dust, motive or quiescent,
nective functions—that Newton investigated the pro-
fluid as infinitely fine matter endowed with repulsive
sure its equilibrium, the particles of which could repel
vith forces that were inversely as their diameters. In
resistances in a single fluid were shown to be as the
fic density of the fluid simply. The experiments offered
are to be found in the scholium at the end of the seventh
nd book, of the *Principia*. For our present purpose
iments show the perfect homogeneity and internal

oscillations. With this apparatus, which is said to have been admirably constructed, he could discover no difference of resistance, after proper correction for the surface of the wire was made, whether the disk oscillated near the surface of the water or at a depth of five feet, although the difference of superimposed mass, and consequently pressure, was immense. Perhaps this is the best experimental evidence that we possess of the perfect physical homogeneity or structural equality that evidently exists in so perfect a fluid as water under great difference of pressure. I do not think, however, that this homogeneity will *entirely* account for the phenomena given by Newton and Coulomb, of equal resistance at all depths, but it does so very nearly. I will, therefore, supplement this by another proposition further on (9 Prop.).

Construction of Atoms forming Fluids and other Bodies.

4. PROPOSITION: *That a simple gas is a fluid composed of atoms, or the smallest divisible parts of matter; these atoms being infinitely tough and infinitely elastic bodies endowed with polar attractive forces by which they symmetrically unite.*

a. The atom may be to human perception a particle infinitely small. It is said that a ten-thousand-millionth part of a grain of one of the densest bodies, gold, can be made a visible quantity to the eye, and that this quantity may be more than multiplied by itself to go to the limit of detection of its presence chemically. So that even supposing this to be the limit of size for the atom, which it evidently is not, the mind is lost in the conception of it, even within manipulatory range of its smallness. Nevertheless the distinct characteristics of atoms as natural bodies may be made evident in many ways, particularly in their power of combination with other atoms in definite proportions, which are found to be generally in equal quantities or multiples of their unit volumes in the gaseous state of the body.

b. It is said to be demonstrable that a solid body, however small, may, by division in parts that may remain in partial contact, fill a space, however great, so that assuming the atom sufficiently small, the gas may be a body of atoms in contact, and in this form possess all its observed or much greater tenuity.

ry known hard body has an elastic surface; if the atom has ace, which deflects under pressure by some function of to the distance of surface impressed, or that the deflection is inversely as the square of the pressure, *this deflection commencing upon contact by a quantity of pressure infinitely small.* The pressures to the volumes of gases could as well be accounted for by this means as by any other, without the necessity of supposing the atom to possess propulsive forces or to act where it is not. There is no physical reason to assume the atom being infinitely *hard* as is general: in assuming it infinitely *tough* and *elastic*, this would equally insure its permanent durability, or it might possess an infinitely hard nucleus and an infinitely elastic surface, which I think is most probable.

d. It is easily seen by the smallness assumed for the atom, that a very small absolute material deflection of its surface would materially decrease the volume of a physically measurable mass.

e. The elastic surface forces of the atom may be *increased* or even *caused* by heat. But it is not necessary to assume that the same amount of heat force per atom should produce an equal elastic envelope about it. There is strong evidence that this is not the case. We know that it takes a much higher temperature to render gold gaseous than it does mercury, and this a much higher temperature than hydrogen, whereas at the gaseous temperatures of these bodies the elastic forces may be nearly equal.

f. It appears to be quite possible that the increase of elastic force about the atom caused by heat is constantly equal to the amount of heat present, so long as the body remains in the same state, although the general dimensions of the body may indicate the reverse of this. Thus, the experiments of Arago and Fresnel show, that although the exceptional body water increases in bulk from 4° Centigrade downwards as well as upwards, by defect as well as by excess of temperature, that both in the time of its descent while it remains liquid, and in its crystalline form as ice, the refraction index of light passing through it increases at all times in ratio to the loss of heat, as though the water continuously contracted, or that the structure of the water became more dense. In this case it appears to me that we must assume so far the action of polar forces, that the refractions are relatively proportional to the molecular structural density, and irrespective of the molecular interspaces shown by the measurable mass of the outer volume.

5. PROPOSITION: *That in a gas the elastic exterior forces of the atom may be partly absorbed at the points of contact by attraction, and form thereby a more dense gas, or liquid, or other material body.*

a. Two volumes of like or of different gases may form a bulk equal to two volumes at equal pressure. In such cases the atomic elasticities are assumed to remain about the atoms in exterior contact, except as they are mechanically pressed together; such mixtures we have in the compound *atmosphere* formed of oxygen and nitrogen.

b. Compound gases may form mixtures at equal pressures which are in volume fractions of their separate volumes, as half, one third, two thirds, &c. Thus two volumes of hydrogen and one of oxygen, that is, *three volumes* united so that they form vapour at say 120° C. occupy the space only of *two volumes.* If we imagine that at the point of contact of the atoms of oxygen and hydrogen the cohesive forces of these bodies (which as chemical forces we know to be great) exceed or in some way *absorb* the greater part of the inter-elastic resistance between the atoms, the elasticities that remain will be now *exterior* only, or principally upon the surface of the tri-unit molecule formed by the force of combination.

c. Two atoms of a gas may unite by polar forces, or otherwise, in a similar manner, to form the bi-unit atom or molecule, and this bi-unit may have exterior elastic surface forces only or principally, as we may possibly presume from chemical combinations is the case with hydrogen, chlorine, and other elements. It is possible that atoms have polar points where attractive forces are only or mostly active, which are special to the particular kind of atoms, but that the elastic forces are equal in all directions about the atoms.

d. As all gases expand equally by equal increments of heat forces from the same temperatures, it is clear that the exterior elasticities here proposed will be equally affected by heat for all simple atoms, so that all bodies in separate atomic conditions of 4 prop. *e* are *equally elastic upon the atomic surface.*

e. It is possible that heat may be the entire cause of the surface elasticity of the atom as just proposed. The atom being without this force infinitely *hard*, and infinitely *attractive* to other atoms; this is onsistent with the known properties of chemical attraction and of at to separate atoms, that is, to expand matter. In this case all tter to be palpable must be coherent (attractive) in its parts in of a large amount of its elastic surface resistance, the sepa- mic or free elastic state being invisible in all matter. It follow that without heat all matter in contact, by this as- uld coagulate and become a perfectly dense solid mass.

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ce in few cases entirely, if in any.

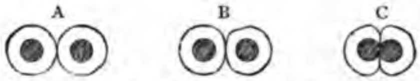

Fig. 1.—Theoretical Atoms.

the diagram above, A may represent a slight atomic of atomic attractions into elastic resistance *per se*, as we may naturally conceive that any mass may be by further attractions of its molecules rendered more or less porous or crystalline, or otherwise molecularly arranged to possess a different structure.

j. It will be readily seen by the above conditions (*g*) that chemical attractions at a certain temperature acting upon two atoms may much exceed the elastic surface resistance, or they may be of such character that these forces of attraction and elastic resistance are in equilibrium by slight indentation of the elastic surface. In the first case the chemical compound will be *stable*, in the second *unstable*.

k. Further, we may assume that compression, by bringing the atomic centres nearer together, will strengthen the atomic attractive forces proportionally, so that in this position the attractive forces may overcome the elastic surface resistances, and form a compound that will be stable, or stable in a certain degree, as a gas may become a liquid or a solid. This may also be effected either by cold, or by cold and pressure.

l. In a static mass or compound, heat forces acting in opposition to the attractive forces of the otherwise stable unit may increase the elastic force, and separate the atomic centres for a certain distance, that is, expand the outward body, yet still, by the superiority of the attractive forces the unit will be to a certain extent stable in its expanded state. On the other hand, in an unstable compound the equilibrium may be such that any increment of heat that may instantly overcome the attractive central force will entirely release the atomic elastic forces. This same effect may also occur from motions of freedom by release of pressure, or by frictional separation, or by vibration. This is the condition of unstable compounds of the explosive class. It is possible that at some low temperature every mass of material is stable, and at some higher temperature every mass is unstable.

m. The attractive forces of the atoms of matter appear to be distinctly different for different elements with respect to themselves and to other atoms, in many cases the densest matter possessing the strongest attractive forces, as with gold and platinum. The aterial with the strongest elastic forces known may possibly be ogen, as this holds its units powerfully apart in the atmosphere, oes not frequently enter into stable compounds, or form hard where it is present in relatively large quantity.

n. When an atom is in such a state of equilibrium with respect to other atoms that its elastic force exceeds the attractive central forces that surround it, it will form *as stable a material or mass as the densest solid*, and the only difference between this state of the body thus formed from that of a solid will be that compression upon its elastic exterior form will react with equal force upon removal of the compression it at first received; whereas compression in a system, with great excess of central attractive over elastic resistance, will increase the central attractions, and be less reactive through elasticity; this last case may be evident for the conditions of a gas, and by the next proposition it will be equally so for a liquid, which may resist pressure with greater force than a solid composed of the same elements at lower temperature.

o. If the atomic surface is infinitely tough and elastic, this, as here proposed, will give perfect elastic reaction, and will be a sufficient cause to preserve the atom as an intact body. The absolute depth of elastic surface from the entire size of the atom will be very small, or certainly not a trillionth of a millimetre. Under the ordinary conditions of pressure of contact a visible elastic body, as india-rubber for instance, would possibly bear more wear than any hard body, and the same would occur with the elastic atom.

p. As a further condition, it is not quite impossible that the atoms of all matter are surrounded with an attractive atmosphere of another matter, ether or some other body, but this is not necessary to support the theory of an elastic, or, if necessary, an infinitely elastic surface to the atom.

q. If the attractive forces between atom and atom act by means of a material elastic envelope which is a part of the atom surrounding it within a certain radius, and the forces of attraction are active by means of this envelope with intensity varying inversely as the squares of the distances from *centre to centre* of the atoms, and that this same entire radius is the extent of the radius of the elastic forces surrounding the atomic nucleus, and that this is active *as resistance* inversely as the square of the distance from the *surface* of an assumed solid nucleus—then the atomic nuclei of two atoms could never touch, as the powers of resistance would become infinite at a point of approach where the attractive forces would only be proportional to the distance approached towards the centre, which, being occupied with perfectly dense matter, it could never reach.

r. The simultaneous action of attraction and elastic repulsion of this proposition may be roughly shown by the experiment of a floating soap-bubble upon carbonic acid gas. The attraction of the earth draws the bubble; the elastic gas resists the attraction, and a point of equilibrium is established for the bubble, where it rests.

Construction of Liquid Molecules.

6. PROPOSITION: *That a liquid molecule being formed of atoms, or of the smallest divisible units of matter, these atoms are united by polar or concretionary forces to form globular molecules of equal dimensions among themselves, which are possibly very large compared to the separate atoms of which they are formed.*

a. As we know that there are solid bodies or masses composed throughout of like materials or elements, it is certain that there must be modes of attractive aggregation by which the large units of matter unite in some special manner to form such masses. In this case the extreme elasticity of the atomic surface would be absorbed to static equilibrium by the attractive forces of the atom, by my theory of a gas (5 prop.). Chemistry furnishes us with abundant proof of the union of matter from such a state of division that it is at first invisible, but that it forms by aggregation or condensation liquids or solids. Indeed matter in its atomic or most divided form appears universally to possess such combining qualities unless these are held separate by other forces.

b. By this proposition I assume that if there exist a mode of atomic aggregation, the effects of attractive forces within a definite radius about separate centres, to which the atoms are attracted, or by which they in any way combine to form a concrete but separate system, that such a system formed of separate equal small masses or molecules, by the separation of parts caused by local attractions within a certain radius, would be a *mobile system*, and in this respect possess functions of fluidity, or it would possibly be a liquid.

c. If the system of atomic aggregation by consecutive attractions is linear or continuous upon consecutive parts, or interlacing or outwardly crystalline, it will by the mode of adhesion of its parts, or of these interlocking with each other, form a solid, or in some instances form a molecular liquid first by separate unit aggregations, and then by further aggregations of such units, a solid.

system here proposed for atomic aggregation to form a
. may be continued in principle to form liquid drops,
m is free from the near cohesive forces of other liquid

n. When an atom is in such a state of equilibrium with respect to other atoms that its elastic force exceeds the attractive central forces that surround it, it will form *as stable a material or mass as the densest solid*, and the only difference between this state of the body thus formed from that of a solid will be that compression upon its elastic exterior form will react with equal force upon removal of the compression it at first received; whereas compression in a system, with great excess of central attractive over elastic resistance, will increase the central attractions, and be less reactive through elasticity; this last case may be evident for the conditions of a gas, and by the next proposition it will be equally so for a liquid, which may resist pressure with greater force than a solid composed of the same elements at lower temperature.

o. If the atomic surface is infinitely tough and elastic, this, as here proposed, will give perfect elastic reaction, and will be a sufficient cause to preserve the atom as an intact body. The absolute depth of elastic surface from the entire size of the atom will be very small, or certainly not a trillionth of a millimetre. Under the ordinary conditions of pressure of contact a visible elastic body, as india-rubber for instance, would possibly bear more wear than any hard body, and the same would occur with the elastic atom.

p. As a further condition, it is not quite impossible that the atoms of all matter are surrounded with an attractive atmosphere of another matter, ether or some other body, but this is not necessary to support the theory of an elastic, or, if necessary, an infinitely elastic surface to the atom.

q. If the attractive forces between atom and atom act by means of a material elastic envelope which is a part of the atom surrounding it within a certain radius, and the forces of attraction are active by means of this envelope with intensity varying inversely as the squares of the distances from *centre to centre* of the atoms, and that this same entire radius is the extent of the radius of the elastic forces surrounding the atomic nucleus, and that this is active *as resistance* inversely as the square of the distance from the *surface* of an assumed solid nucleus—then the atomic nuclei of two atoms could never touch, as the powers of resistance would become infinite at a point of approach where the attractive forces would only be proportional to the distance approached towards the centre, which, being occupied with perfectly dense matter, it could never reach.

r. The simultaneous action of attraction and elastic repulsion of this or three times so as to mix the alcohol with the water, and it be then inverted so as to leave the fine tube upwards, there will be seen a vacuous space, indicating that the fluids have decreased in volume by admixture to this extent. It must be observed that the mixture of alcohol and water is not a chemical mixture, as by applying heat the spirit will evaporate and the water will be left. In this matter we could have arrived at the same conclusion by noting the separate specific gravities of absolute alcohol and of water, and finding the difference of specific gravity in the mixed compound, but this experiment shows the conditions more clearly. The compressibility of fluids is possibly proportional to the porosity or separation of the molecules.

Some Evidence of Polar Forces in Fluids.

7. PROPOSITION: *That a fluid under the action of chemical attractions which are at the time producing molecular changes will diffuse the chemical attractions throughout the fluid with forces proportional to the polar or directive vigour possessed between the combined or compound molecule and the more simple uncombined molecule that has not been under the special chemical action. A liquid or a gaseous system will not be in symmetrical polar equilibrium until the chemical forces are distributed equally in all parts of the mass.*

a. The conditions of attraction and repulsion (elastic force), which ultimately give static position to a molecule in a fluid, may possibly be best observed under conditions of chemical change. This proposition is introduced to give evidence of polar or directive action during this change.

b. A liquid in effervescence, or in ebullition, or under chemical change, is obviously not in a state of symmetrical equilibrium as proposed for a static liquid in the last proposition. There is nevertheless most probably a constant tendency to equilibrium, which is more or less complete in parts of the mass, but so long as there are polar molecular forces in a system not in attractive contact with opposite polar forces in other molecules, the system will be unstable.

c. That liquids possess polar forces of the same kind as those we
a globular piece of loadstone, may possibly be best inferred
tion of a corrosive liquid upon a solid which it has the
ssolve, in cases where a newly constituted liquid is
a chemical compound of the two bodies present; the

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polar or attractive forces of the liquid. This is clearly
if the corrosive liquid has equal affinity in all directions
this affinity would cause the liquid to unite to the sur-
olid, and remain in this position attached to it simply,
the surface of the solid was completely attached to
nd thereby covered by a stratum of it, no other mole-
cohesive liquid, for want of space to approach, could
tact with it. It is possible that this really occurs in
, as with silver in hydrochloric acid, zinc under aerial
c. But for the solution of a solid body in a liquid it is
t only that the molecules of the corrosive body should
to unite with the solid, but that this adhesion should
nstant possess some *mode of force* by which the new
med by combination is immediately detached from the
r that another molecule of the corrosive liquid may be
ach and to unite with the surface of the solid in the

to be in unstable equilibrium in the liquid, so that it will be driven in like manner to the first departure from other molecules that have not been in contact with the solid, and the neutral molecule formed after combination would *back out*, as it were, from the presence of the solid to permit the corrosive attractive molecule to approach. This being the case, a molecule, after combination with an atom of the solid, would not find rest in polar position until it reached the most distant part of the liquid system from the solid it at first corroded. We may conclude, nevertheless, that the intensities of polar forces may be very different in the direct action of a corrosive liquid upon a solid to the intermolecular polarity in the liquid afterwards, as the polar forces in the new molecule may be very weak. For many reasons, particularly from the fact that dense compounds do not mix, I anticipate the polar forces in a neutral liquid to be excessively weak, or even outwardly impalpable.

g. What I infer from the principles of the above, by the conditions under which the action of a corrosive liquid upon a solid forms a new liquid, that is, a newly constructed molecular mass, that such may be the general formation of other liquid molecules either of simpler or more complex structure. The forces of atomic polar cohesion being distributed until a symmetrical liquid is formed possessing molecular polar forces which act directively, and produce its general cohesive and other physical properties.

h. Under the conditions discussed above, the final disposition of the molecules of a liquid would be by symmetrical arrangement, consistent with the polar forces of its separate molecules, and this would hold for all static liquids, that is, liquids not under the influence of chemical changes, as it would hold also for the liquid as soon as the chemical change ceased. The evidence of this being the case would no doubt be difficult to prove, except by inference that nearly all bodies that we are able to observe in a solid state, if pure, assume symmetrical forms (crystals), and it is most probable that such symmetrical form as we witness in the crystal is a continuity of like symmetrical or orderly construction in the liquid from which it is derived. In the case of solids that appear to be homogeneous, Dr. Tyndall has devised a beautiful experiment, the dissolution of the centre of a pure apparently homo-
block of ice by the focus of a burning-glass, in which ex-
as the ice dissolves, its crystalline structure is rendered
he well-known forms of ice crystals that start into view.

same conditions will also apply where the body is dissolved without chemical composition.

d. If we place a corrosive liquid in contact with a solid that it has power to adhere to and to dissolve, the solid will be dissolved into the liquid, and the original polar system, or cause of attraction, which produced the cohesion of the solid, will be changed or dissociated by the polar or attractive forces of the liquid. This is clearly the case, for if the corrosive liquid has equal affinity in all directions to the solid, this affinity would cause the liquid to unite to the surface of the solid, and remain in this position attached to it simply, so that when the surface of the solid was completely attached to the liquid, and thereby covered by a stratum of it, no other molecules of the cohesive liquid, for want of space to approach, could come in contact with it. It is possible that this really occurs in certain cases, as with silver in hydrochloric acid, zinc under aerial oxidation, &c. But for the solution of a solid body in a liquid it is necessary not only that the molecules of the corrosive body should adhere, so as to unite with the solid, but that this adhesion should also at the instant possess some *mode of force* by which the new molecule formed by combination is immediately detached from the solid in order that another molecule of the corrosive liquid may be able to approach and to unite with the surface of the solid in the same manner as the first particle approached and united with it.

e. It is necessary to complete the total effect observed, in addition to the causes offered above, for the solution of a solid in a free liquid, that the corrosive particles should have a mode of approach and a mode of retrogression, as we find a solution of a solid in a corrosive liquid will often maintain the liquid in all parts of approximately equal strength. Now if a liquid were a homogeneous system without molecular construction, it would approach the solid upon which it acted *en masse*, and there would be no change of parts except quite locally. It therefore becomes probable that the molecule of the solid, at the instant it is attracted, has its polar forces displaced at the point of contact by the more attractive polar forces of the liquid molecule, so that now the elastic forces of the solid atom react and throw this off the solid mass, to which it was before united by the elastic forces set free from polar cohesion.

f. We may also conceive that by the same system of forces acting with less intensity, when the newly formed molecule is free, that this molecule will possess new polar forces which may cause it composed of like matter, and that motive resistance would then only vary as the density of these fluids. That such equivalence of principle exists in fluids I shall endeavour to show by experiment as we proceed.

b. For the principles of the proposition I assume that the gas is a finer division of matter (as offered, 4 prop.) than the liquid, possibly separately atomic, or united in its free state by weak polar or other forces in bi-atomic or tri-atomic separate molecules (5 prop.), the atoms being perfect solids, infinitely tough and infinitely elastic at their surfaces; and that the liquid is formed of molecular concretions, which may be crystalline, conglomerate, or otherwise united, so that by absorption of elastic surface forces of the atom upon certain points of contact, they are relatively to the gaseous matter large combined molecular masses (6 prop.). By the present proposition, in the construction of a liquid molecule the molecular aggregate is assumed to be surrounded by an atmospheric system of gaseous atoms which are *adhesive* upon it through the continuity of the attractive forces diminishing from the centre upon which the entire concrete liquid molecule is formed. The gas that surrounds the large liquid molecule may be either a separate gas, or a gas formed of the same material as the liquid by a difference only of a more open arrangement of the atomic parts, in which case the surrounding gas may be termed a vapour. This vapour being in adhesive contact upon the liquid molecule, a more perfect gas may in some cases further surround this exteriorly.

c. In this theory of a liquid, it will be seen that the difference of the sizes of the molecular concretionary nucleus, and its more attenuated surrounding gaseous parts, would be alone sufficient to account for the same equivalent mobility in a liquid system as that observed in a gaseous one, as the gaseous system would be *exterior* to the larger liquid molecule. For we might in this case either assume that the gaseous matter, held by weak attraction or cohesion, acted by the freedom of its parts, caused by their fineness and separation, as a *lubricant to the motions of the larger molecule* of the liquid proper, or that the liquid molecule *floated* as it were in the more attenuated matter of the gas. Upon this principle the whole system

r of the liquid as before proposed would be moved only
ontact of solid parts, and the phenomenon of repulsion
e a *necessary principle to be assumed,* or any greater
to exist than the conditions of known polar forces

I may here remark that I do not assume that liquid symmetry is necessarily or generally *crystalline*. I assume that this is the special condition of solidity, but that the molecules of liquids are held in position by polar forces which are equivalent to the same polar forces that produce a crystalline or solid mass. The probable symmetrical forms of liquids I will discuss further on.

i. The only known evidence that may possibly exist of the symmetry of the system of a liquid may be inferred from the similarity of effect upon light to absolute crystallization which we witness in certain liquids, as, for instance, in sugar solutions under polarization. Perhaps many liquids under severe tests would also exhibit polar forces to light. In such cases I presume the polar forces are internal, and do not affect the general principles of attractive cohesion in the liquid molecule, which is exactly or very approximately equal in all directions, and that these polar forces are no more than sufficient to place the molecule in a state of symmetrical equilibrium if free from external forces.

Uniformity of Cause of Fluidity for all Matter.

8. PROPOSITION: *That the fluidity of liquids is dependent upon the presence of gases, or of liquid vapours held by attractive forces upon the molecular surface and intruded intermolecularly.*

a. If every concrete molecule of a liquid (6 prop.) were on a very small scale constituted exactly as the terrestrial globe we inhabit, it would be surrounded by an atmosphere of gas or vapour. If we imagine that the central attractive force of such a molecule towards other molecules as here imagined were very weak, say proportionally to its size in relation to that of the earth, then a number of such molecules thrown together in a space free from gravitation would each maintain its atmosphere with only slight impression upon it by the weak mass attractive forces of the other molecules against it. This is equivalent to the conditions I have imagined for the atoms forming a gas, by these atoms being surrounded by an elastic surface (4 prop.). If we can apply the same principles to the larger molecule of a liquid as the gas, assuming much greater central density and comparatively larger central mass of the liquid by atomic concretion (6 prop.); then we could conceive that there would be uniformity of motion in gases and liquids by impression of like forces upon or within these fluids as regards the friction of displacement of their molecular systems *inter se* by their surfaces of contact being composed of like matter, and that motive resistance would then only vary as the density of these fluids. That such equivalence of principle exists in fluids I shall endeavour to show by experiment as we proceed.

b. For the principles of the proposition I assume that the gas is a finer division of matter (as offered, 4 prop.) than the liquid, possibly separately atomic, or united in its free state by weak polar or other forces in bi-atomic or tri-atomic separate molecules (5 prop.), the atoms being perfect solids, infinitely tough and infinitely elastic at their surfaces; and that the liquid is formed of molecular concretions, which may be crystalline, conglomerate, or otherwise united, so that by absorption of elastic surface forces of the atom upon certain points of contact, they are relatively to the gaseous matter large combined molecular masses (6 prop.). By the present proposition, in the construction of a liquid molecule the molecular aggregate is assumed to be surrounded by an atmospheric system of gaseous atoms which are *adhesive* upon it through the continuity of the attractive forces diminishing from the centre upon which the entire concrete liquid molecule is formed. The gas that surrounds the large liquid molecule may be either a separate gas, or a gas formed of the same material as the liquid by a difference only of a more open arrangement of the atomic parts, in which case the surrounding gas may be termed a vapour. This vapour being in adhesive contact upon the liquid molecule, a more perfect gas may in some cases further surround this exteriorly.

c. In this theory of a liquid, it will be seen that the difference of the sizes of the molecular concretionary nucleus, and its more attenuated surrounding gaseous parts, would be alone sufficient to account for the same equivalent mobility in a liquid system as that observed in a gaseous one, as the gaseous system would be *exterior* to the larger liquid molecule. For we might in this case either assume that the gaseous matter, held by weak attraction or cohesion, acted by the freedom of its parts, caused by their fineness and separation, as a *lubricant to the motions of the larger molecule* of the liquid proper, or that the liquid molecule *floated* as it were in the more attenuated matter of the gas. Upon this principle the whole system ter of the liquid as before proposed would be moved only contact of solid parts, and the phenomenon of repulsion be a *necessary principle to be assumed,* or any greater y to exist than the conditions of known polar forces in fluid matter would warrant. The separate atoms in the gas, by their smallness and interspaces being assumed to be arranged to globular form around the liquid molecule would produce an extensile elasticity in the liquid proportional to the number of surfaces in contact.

d. For the passage of molecular matter from a gaseous to a solid state, and *vice versa,* it is not necessary to assume the intervention of the liquid state, or certainly not in all cases. But it is almost certain that all matter may exist in a gaseous as well as a solid state under varying conditions of temperature and pressure. Of the passage of the gases directly from the solid under atmospheric pressure such instances may be taken as the evaporization of iodine, camphine, ammonia carbonate, and some other bodies wherein gases are thrown off solids directly at low temperatures. Under greater pressures, at melting-points, with the same bodies a liquid may be formed as a gas under less pressure, as is the case with arsenic. It is probable that the liquid is generally a *re-formation,* the gaseous being the first form of molecular separation; the liquid concretion being by a new arrangement of polar force (6 prop.) partly dependent upon the vapour pressures upon the evaporating or dissolving solid. This may be inferred in that if the vapour forces are removed as quickly as they are formed, as in the case of evaporation of snow in dry winds, the intermediate state of liquidity does not intervene. And the same may be inferred in the melting of zinc, aluminium, iron, and other metals, where these bodies inflame if not retained by a flux or by a coating of their own oxides sufficient to form a solid or liquid pressure immediately upon them.

e. It is further possible that liquids of all kinds either form gases by evaporation of their own molecules, or imbibe certain quantities of such gases as may be presented to them, as may be consistently adherent to their systems. Mercury, the densest of all permanent liquids at ordinary temperatures, has been found to emit vapour at its free surface sufficient to discolour gold placed above the surface. Faraday has shown that this evaporation occurs in mercury down to a temperature of 4° Centigrade at a *sensible distance* from the surface. It is probable that vapour of higher density exists at insensible distances, that is, *intermolecularly* and upon the *immediate surface* of the molecule of mercury, so long as heat force maintains the mercury liquid, and probably after this.

f. This intermolecular space, if I may so term it, in liquids that

I assume to be occupied by vapours or gases is possibly a nearly constant quantity. This is inferred from the quantity of gas that a liquid absorbs, that is, as I assume, attracts to surround its molecules, and is proportional to the pressure upon the gas. And as the density of a gas varies approximately as the pressure, it follows by this proposition that a given liquid always absorbs or collects by the radius of its attractive forces a constant volume of gas *per massa*, whatever the pressure, according to Dalton's law: by my theory *the quantity being that represented by a certain depth of gas upon the area of the surface of the liquid molecule.*

g. Where a liquid by loss of heat forms a solid, the solid so formed, although generally of less bulk, is a body *unlike the liquid;* it is generally *compressible by small forces.* In this case I assume that the perfectly rigid solid atoms that formed the symmetrical gas, or the liquid, by structural arrangement or polar force about the concretionary liquid molecule are now crystallized, as it were, upon the molecular surfaces in more compact form by suppression of a part of the atomic elasticity in the gas or gaseous envelope, so that the atomic atmosphere is now concrete upon the solid molecule. The cause of the permanent atomic surface deflection in this case being derived from the force of chemical attraction present by loss of heat-elasticity, so that what was formerly the liquid molecule is now the solid molecule, the gaseous envelope being now deposited upon it; this gas has therefore no longer the symmetrically distributed structural matter, or the force, to offer the resistance it offered before.

h. We can imagine that the dense molecular system of matter that a liquid is proved to be under pressure, that if it were formed physically of molecules of equal forms which were as particles of dust, such an equal system would form an immobile mass; but if we can conceive that such a system can by its molecular attractions, or otherwise, compound with it another less dense molecular system whose individual atomic forces are as the diameters of their atomic masses, that these will disjoint, as it were, the equality [illegible] the more rigid system, and cause its molecules to float or move in [illegible] elastic atmosphere easily; the intervening gaseous or vaporous [illegible] being by its tenuity more mobile than the entirely con[illegible]ry molecular one. In such a form the relatively large of a liquid would be free, or very nearly so, of polar forces, he attraction forces to be satisfied, and to be equal in n upon the gaseous envelope.

sible that by the gaseous intrusion which occurs in the air with water, that we have water as a very mobile fluid, at ordinary temperatures, the air acting, as before mentioned, as a mechanical lubricant to the larger molecular aqueous system proper. However, this would not exclude the condition I propose, that water may be mobile principally from its large molecules being surrounded by their own vapour. That the fluidity of water depends in a great measure upon the presence of air, is shown in the researches of Donny, in his celebrated experiment, which is as follows:[1]—A clean metre long, closed at one end, is bent in its centre rms two arms, inclined at an angle of about 60 degrees er. The tube is for about two-thirds of its entire with water, and the open end of the tube is now d over with the blow-pipe. The tube is placed so as to sed end lowest, and in this position the water in it is n hour or more, so as to expel as much as possible of s contained in the water. When the water in the tube g, and the space above it is well filled with steam, the he tube is closed by the blow-pipe, and hermetically

's Vacuum

if it is surrounded by the gas, this will produce an hydrostatic pressure about the molecule, so that the vapour assumed to be nearest to the molecule will be absorbed by the molecule, and the gas only remain surrounding the vapour. Or if the absorbed gas be one of great adhesive force to the liquid molecule, a part of the gas may be liquefied upon its surface by near attraction. The system proposed is shown diagrammatically above of liquid concretionary molecules. In this illustration the molecule is supposed to be surrounded by a vapour close to it, with a general atmosphere of gas surrounding the entire system as it would be under pressure.

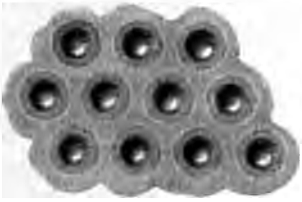

Fig. 4.—Theoretical Molecular condition of a Liquid.

k. Taking a purely hypothetical view of the subject, I do not see great improbability that this system of gaseous atmosphere about the molecule does not extend to all matter including solids. In which case we may conceive that, as the diamond is harder than graphite, that this may be, that its elastic surface force or vapour force is less, or was less by near attraction through the great pressure existing at the time of its formation into a set solid, thus giving a closer or more attractive mode of atomic aggregation, and a greater suppression of elastic resistance. In the same manner a hydrocarbon may be formed of a molecule of carbon surrounded by an atmosphere of hydrogen partly condensed upon it to form a liquid as an oil; or in another case, a molecule of carbon may be surrounded with an adhesive atmosphere of hydrogen or of oxygen to form a gas. This might be true assuming carbon to possess extremely small, extensile, elastic, or evaporative force at the surface of its atom.

l. If molecules of matter, particularly plastic and liquid matter, separated by vapour force, capable of a certain amount of con- tion upon the molecule, *then expansions by heat forces will be as of evaporation of the separate molecules, and minus heat con- us the powers of condensation*, which are generally inversely at a liquid or solid molecule at a certain temperature certain vapour or elastic force about itself, but at a erature, by the same continuous process, which may engthening of elastic forces at the surface of its atom, holly dissipated as vapour, either in a system of finer vision or in certain cases by heat forces and relief of attraction, possibly in separate atomic division; the ms being then held by their own forces in sym- ar positions, beyond which further expansion could any amount of heat force.

construction of liquids I have taken the surrounding s in this proposition to be equal, therefore the central action or adhesion of the vapour to the liquid molecule on all sides. I anticipate, nevertheless, as before pro- here is a certain amount of polarity or directive force ecule of matter to other molecules, which I have before iquids by the systematic polarization of light by sugar lutions. But as this probably does not generally in the nolecule exceed the effect of polar forces of the earth general attraction of gravitation, I conceive the average ule to be equally attractive to its vapour or gas on all earth may be to its own atmosphere, although the nd the earth may have directive or attractive polarity ndent of this for position of its parts in relation to each

Sensitive Mobility under Pressure.

9. PROPOSITION: *That the mobility of a fluid varies directly as the elasticity in the atomic forces surrounding its molecule. The elasticity being in sensitive equilibrium proportional to the pressure upon the fluid.*

a. In the above I am compelled to use the word atomic to distinguish a finer system of gaseous matter that may surround a gaseous molecule, but I do not assume that the atomic system is necessarily *separately* atomic, although I see no reason that it should not often be so. For a liquid molecule we may assume a gaseous envelope only, as offered in the last proposition.

b. This proposition is offered to meet a difficulty, as it appears to me, in explication of Newton's and Coulomb's experiments given 3 proposition, *d*, *e*, for although the homogeneity or equality of resistance at all depths in a liquid is clearly demonstrated, this equality does not appear to be rational with an equality of attractive or repulsive forces in separate molecules, or equality of mobility of contact of the molecules or parts simply *per se* from any cause. For if we consider the mobility from any cause equal about the molecule under all conditions, we must neglect the effect of pressure of the mass above a lower molecule, which pressure being derived from material parts of the same mass, should act as a resistance to the freedom of motions of displacement to the lower molecule. It therefore appears to me probable, that there is a natural line for fluids as defined by the proposition, by which the molecules of fluids are in more *sensitive motive equilibrium under greater surrounding elastic pressure.* This, it appears to me, would also very well account for one cause of a kind of immobility, that is very evident at the surface of a liquid, which is seen to move as a concrete system, when small objects of great specific gravity float upon it, some other conditions of which I will consider in the next chapter, in discussion of surface forces.

c. Assuming the molecular elastic surface by equality of central attractions perfectly smooth, which I think most rational, we may find evidences that mobility of contact will be relatively greater under greater pressure in solids, which would be from the greater [illegible]tiveness of compressed surface elasticities upon contact. Thus v lean a light body with a hard point, as the point of a pen t handle, at an angle of from 20 to 30 degrees, upon a perhed hard surface of glass; but if we press the upper end it will instantly slip down, or if we lean a heavier body with the same surfaces of contact, it will not maintain itself at so great an angle to the surface.

d. Another simple experiment will demonstrate the same fact. If we cut three or four pieces of clean smooth paper, of exactly the same size, and place them lightly upon a clean surface of glass, one by itself, and two or three superimposed; and then raise the piece of glass at one end to form an angle, at which the pieces of paper begin to slip, the heavier parcel will begin generally to slip first. The same will occur with pieces of moderately stout flat metal and with metal foil, and in vacuum as well as in air.

e. It is possible that the velocity of sound through bodies is wholly due to the sensitiveness of compressed elasticities acting in direct lines, caused by the strength of cohesive attractions into the surrounding elastic surfaces of the atom or molecule in these lines; so that the velocity of sound is great and sensitive in steel, glass, and other hard bodies; but slow and insensitive in gases, being most insensitive in hydrogen. These conditions on the whole will be subject to the molecular construction of the body taken.

Mode of Molecular Aggregation for Liquids.

10. PROPOSITION: *That the molecular system of a liquid, assuming each molecule surrounded by its vapours, has its molecules symmetrically arranged by polar forces in such a manner that the greatest number of molecules, or molecular systems, may be contained in the space that the liquid occupies.*

a. The molecular system here proposed would be represented as in the engraving below at Fig. 5, the large liquid molecules and their vapours being represented by circles so arranged; and not as at Fig. 6, where the polar forces retain the molecules in a vertical series, although I see no reason that some forms of matter should not be so arranged or changed to such form as by cooling, where bulk is increased thereby, preliminary to crystallization.

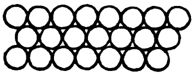

Fig. 5.—Molecules.

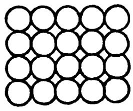

Fig. 6.—Molecules.

b. The same form of molecular construction as that shown at Fig. 5 has been illustrated for that of a liquid by Newton, Bossut, and others. It is here introduced to consider a condition that renders it most probably the actual system, which is, that for liquids (and fluids generally) lateral pressures upon containing vessels are as the heights of the column of liquid above any given point. If the molecular system of a liquid were as that shown Fig. 6, this would not be the case, as every vertical range of molecules would be supported upon the lowest molecule, and very small lateral pressure would keep the column vertical, so that the pressures upon the sides of a vessel would be small and that on the bottom great. But if every molecule were held in its position by forces that were not vertically axial, these pressures would be equally lateral forces, so that the limiting lateral surfaces would aid in supporting the system. And in this, the whole system being assumed elastic and mobile in all its parts, would be as a flexible system, and all parts at equal depth would receive equal pressures.

c. Thus let A A′ be a lateral surface, and all the shaded molecules press by their gravitation downwards, and the unshaded molecules rest against the lateral surface. Then the lateral particles would be pressed outwards by the vertical force of the contiguous molecules, and it would be clear that to press these molecules by this lateral surface further into the system, we should require a force sufficient to lift up all the particles above. In this manner the lateral particles would be jambed against the sides of a vessel, and the jamb, in a perfectly elastic mobile system, would be a pressure equal to the gravitating force of the mass above. In the same way it will be seen also that this jamb would produce an equal upward pressure, or pressure in any other direction than that which merely supports the weight of the fluid, if the area of pressure were restricted by the form of the vessel.

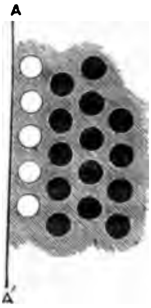

Fig. 7.—Molecules of Liquid against a Vertical Solid.

d. The above hypothesis is consistent with the fact that a continuous fluid resting upon or pressing against a plane surface exerts a force directly perpendicular to this surface, this force acting as a essure equal to the greatest pressure per area upon any part of uid that can be compressed by the force of gravitation at equal Thus if we perforate a hole through a thin vessel contain- id, the liquid is projected directly perpendicular to the e vessel, with a force of projection equal per area to the weight of the liquid above the hole, that is, equal to the greatest pressure per area that gravitation can effect in any part of the mass system of the liquid at equal depth with the hole. This principle is rendered important in consideration of directive motive forces which will be hereafter considered.

e. If such symmetrical molecular action as here proposed exist, this may either be derived wholly from a general principle of cohesion which draws the greatest number of molecules about any single molecule, the principles of which I will discuss in the next proposition, or from this and polar attractions conjointly active at several points of the molecule, the principles of which may be inferred from the disposition of matter to take crystal forms.

f. The same form of molecular arrangement as that illustrated above would possibly occur from pressure upon a system of globular molecules. But not necessarily so unless there were present the polar forces assumed. As, for instance, a vessel filled with rapeseed or with globular shot would not have its separate units so arranged by chance, or unless immense trouble had been taken to produce this arrangement, whereas with polar forces acting symmetrically at certain points of every molecule this might be the necessary or only possible arrangement.

Equal Universal Cohesion of Liquid Molecules.

11. PROPOSITION: *That the cohesive forces of liquids are caused by molecular surface attractions, which are active in producing adhesions of the greatest superficial area of contact possible upon all the molecules of a liquid system, of which each molecule forms a symmetrical part.*

a. The above proposition, as far as I have been able to observe, is a *law of liquid cohesion*, that is particularly valuable when applied

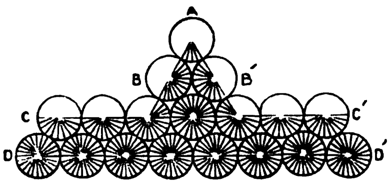

Fig. 8.—Molecular Attractions to form Mass.

to the conditions of surface forces which I will hereafter consider, the matter beng now taken for the unity of masses only.

b. Let the figure above represent any exterior surface of a molecular liquid system having attractive cohesive forces. Let the cohesive attractive forces reside in every molecule, and act upon the nearest molecules of its own mass system, and further let these attractions be equal in every direction from the centre of each molecule to its area of contact, and for a certain space surrounding this, as shown by radial lines from the centres of the molecules in Fig. 8, neglecting any possible influence of local polarity, which I assume would be very weak in the liquid molecule, and suppose, also, all action of gravitation suspended as a separate force acting upon the system; then will the molecule A be out of central equilibrium to the system, and exert a direct attractive force upon the system towards the molecules B B′, and the molecules B B′ will exert an attractive force towards the plane C C′ and towards each other with a small force only towards A, so that these molecules also will be out of central equilibrium. For the conditions of the molecules C C′, these will exert attractive forces towards D D′, the mass system, and lateral forces towards each other; they will therefore be out of central equilibrium but in *lateral equilibrium*. Under these conditions they will represent the greatest area of radial forces possible for the surface of a liquid system. The molecules of the plane D D′ as a part of the mass will be surrounded by equal radial molecular forces, and will therefore be in perfect central equilibrium at every point of the molecule.

c. Now returning to the consideration of the motive forces derived from attractions in the molecules A and B B′, these will act as certain forces in ratio to their attractive *area* upon the lateral equilibrium of the plane C C′, and indirectly through the plane C C′ upon the perfect equilibrium of the plane D D′, and if these planes are perfectly mobile and capable of extension, these molecules A and B B′ will sink into the mass system and form molecules either in lateral equilibrium in the surface system C C′, or of perfect equilibrium in the plane D D′; the law being satisfied *that the molecule has found the greatest area of surface adhesion possible for a free system of liquid matter.*

d. In the above proposition it must be distinctly observed that force of gravitation forms necessarily no function of the system oposed; the condition of this for liquid surface will be here-sidered. A liquid, if its molecular attraction or cohesion t to support its mass, forms a smooth surface in any posi-instance a varnish laid on a vertical surface or an inverted horizontal one, and the same will occur with water or other liquids. The splendid experimental researches of M. J. Plateau may be used to assure us of the principles of the above proposition, that the molecular cohesion that we witness in liquids is a force of continuity of physical attraction or cohesion of the molecules which forms the liquid system; and that this attraction or cohesion is independent of the density of the mass, or nearly so. The important experiment which proves this is shown in that a free molecular mass of liquid in equilibrium is in no way influenced in its motion by the presence of denser matter within its mass system.[1]

e. The most important experiment, by which the general equilibrium of forces in a liquid mass is shown by M. Plateau, is by taking two liquids of exactly equal specific gravity that are found to unite only in a slight degree with each other, and by placing a mass of one of these liquids of any form in a central position within a larger mass of the other. In this case the central mass forms a perfect globe. The liquids employed by M. Plateau in these interesting experiments are pure olive-oil for the one and a mixture of alcohol and water of exactly the same specific gravity as the oil for the other. By injecting the oil with care in the centre of the mass of dilute alcohol by means of a glass syringe the oil is found to draw itself together, and a perfect globe is formed, which is supported as a free body in the diluted alcohol.

f. That the above is not a *mass attraction* M. Plateau's important experiments before alluded to show, as he finds that by placing a stout plate of iron of nearly the same diameter as the globe of oil in its centre, by means which he points out, the presence of this heavy mass is found not to deform the external figure of the perfect globe in the slightest degree.

g. M. Plateau attributes the perfect equilibrium of forms which his experiments demonstrate for free liquid matter to be caused principally by *surface tension* of the mass system as originally proposed by Segner in 1751; and his experiments in some cases that he offers go very far to show that this would represent a sufficient cause if active to the necessary extent demanded, the interior inertia of a mass system being assumed to be in such a general state of free equilibrium as to be entirely directed by the surface tension. It nevertheless appears to me that as a general system of cohesion exists in all liquids, as shown clearly by the phenomena of traction, in which the parts of liquids follow each other with evident force, as they also in the same manner adhere to solids, so that the surface tension cannot be the entire cause of cohesion in the system of matter of a fluid any more than of a solid. On the other hand, if the molecule seeks the *greatest area* of surface attraction in a perfectly free liquid, as here proposed, this principle of cohesion alone will ensure the perfectly globular form for any free unit mass of liquid of the same cohesive system subject to molecular forces only.

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[1] *Statique expérimentale et théorétique des liquids soumis aux seules forces moléculaires,* 1873, by J. Plateau, § 13.

h. I do not think the conclusion I arrive at, that molecular masses may be held by cohesive forces simply, *if this be true*, detracts in any way from the value of M. Plateau's splendid experimental researches. I only think that the symmetry of molecular forces in a liquid has more to do with the symmetry of free molecular aggregate forms, in any case, than surface forces taken simply as such. I conclude this among other reasons, in reference to the theory of tensile surfaces, by the *slowness* with which an undoubtedly *tensile film* of a soap-bubble contracts when the interior of the pipe by which it was blown is left open for it to do so. The tension of the two liquid surfaces of the film in this case, the exterior and interior being active as lineal attractions upon the resistance of the small volume of air in the interior of the bubble only, shows that with large surfaces of tension, and very small mass to be moved, the tensile force judged by its active velocity in this case must be *extremely weak.* Whereas the motive forces that form the globular mass of oil by moving its heavy bulk quickly to equilibrium of figure, in M. Plateau's important experiment just mentioned, indicate a much greater constant force in the liquid, for it to be able to overcome the general inertia of its large mass, than could be due to the influence of any weak surface force, such as we find able to act only feebly upon the small mass of a film, having exposed surface on both sides open to this action.

i. If cohesion be powerfully active in the manner I propose, the
ame molecular aggregative forces as are actually observed would be
oduced in free molecular matter, as by any form of surface tension,
even of *surface distension* of a liquid; if the central mass be
together by the general cohesive force that all liquids possess.
d be also clear that the globular form would be the only one
satisfy the conditions of perfect equilibrium in a free mass
les proposed *a.* Under these conditions also, inclosed

masses of more or less dense adherent matter, would no more interfere with the system, than if the force were considered to be an exterior tension upon the surface, unless such masses protruded, when the conditions would be altered for all cases. It will be further evident that the proposition I have made above for the cohesive system of a liquid really becomes active as a surface force; but it does this independently of assuming a special condition necessary for the surface molecular cohesion possessing greater activity than is otherwise indicated by experiment; which may possibly be attributed to a superior viscosity at the surface for water, but could not be so for oil, where cohesion is found to be equally active, as M. Plateau's experiments otherwise show. See works referred to, § 269.

j. Perhaps some evidence of the law offered in this proposition may be discovered by taking the conditions of a body in which we can scarcely imagine any distinct conditions of surface force to be present, or at least to be sufficiently active to overcome the general cohesion or viscosity of the body taken. The best illustration that occurs to me would be the very viscous liquid, melted glass, which we know may be drawn into very fine threads, by strain upon the internal cohesion of its system without any disturbance from surface forces being scarcely imaginable to be active upon it. Now, if we take a thread of glass and hold this in or near a flame, until it begins to melt, it will be found that the melted part instantly *seeks the greatest area of intermolecular cohesion,* that is, it assumes a globular form, if not prevented by the force of gravitation from doing so by the position in which it is held.

Special Qualities of Water and Air.

12. PROPOSITION: *That the fluids water and air, possibly by the molecular elasticities of their systems and by polar forces, possess a certain amount of elastic rigidity of the same kind as that observable in gelatinous bodies.*

a. By the molecular structure proposed for a liquid (8 prop.) every liquid system, by the elasticity of its molecular surfaces will possess a certain amount of flexibility of mass derived from its chemical and physical qualities; which I assume to be different for liquids of different kinds. Besides which I imagine that there are present weak polar forces in all fluids (10 prop.) that will produce a certain amount of rigidity within the radius of mobility of a liquid or other flexible system. From these conclusions, and by experimental inerences that water and air possess the property of *rigid flexibility* greater than other fluids relatively to their densities, that is, in those that I have examined, and as I intend, as before mentioned, to follow experiments in air and water principally, I wish to distinctly distinguish this property by a word, for which I propose *gelatinity*. This property has been already inferred to be a quality of water in the bent-tube experiment of Donny given page 24 *i*, as observed in the sluggish movement of the water in the tube and its rigid state when the surface of it is rendered adherent. The same property may be observed in a less degree when the water is in a more fluid state by natural aeration. The property that I suggest appears at all times to give to the water a kind of static mass rigidity greater than its general fluidity, or the mobility of its system, or its density in relation to other fluids would indicate.

b. The property indicated above has been generally included in the term *viscosity;* but this does not very clearly define it, to my mind, as by viscosity, we understand from general definitions, a certain clamminess or stickiness after the manner of varnish, treacle, hot glue, or oil. Bacon gives a definition of this when he says, "Holly has so *viscous* a juice that they make birdlime of the bark." The physical state of both water and air at ordinary temperatures appears to me in experiments to be better expressed as above, by *gelatinous* than *viscous*. The gelatinity I conceive to be somewhat after the nature of cold jelly scarcely capable of settling, and of a higher degree of mobility. This property is apparent in water in the adhesion with which it supports the spherical conditions in drops resting upon solid or liquid surface, in which the drops do not appear to enter into or adhere with any similar property to that observable in really viscous bodies, unless some force is applied. Further, after adhesion is effected with water by any means to a surface it becomes complete, and equally resists removal as we find is the case with gelatinous bodies. Some experiments of Count Rumford led him to infer that a pellicle or film was formed at the superior and inferior surfaces of water, by that which he concluded was a special natural cohesion of the fluid at the surface, and by this he accounted for that peculiarity of surface resistance by which bodies that are fically heavier than water will float upon its surface. This v of *gelatinity* that I propose to adopt, will offer the same f surface resistance, as we find that *jellies* resist at the sur- cous bodies do not. Reserving for the present the discussion of some causes of surface resistance, I may mention one of Count Rumford's experiments. He poured a quantity of sulphuric ether upon the surface of water in a vessel, and placed gently in the ether several bodies of greater specific gravity than the water, as a needle, particles of tin, and globules of mercury. These all descended through the ether, but floated upon the surface of the water. It was quite observable that these bodies pressed down the surface of the water, and little hollows or bags were seen beneath them. These floating bodies were made quite clean, and the water adhered persistently to them when they had once entered it. Indeed similar resistances were observable when the like bodies quitted the water. It is therefore from no material repulsion inherent in these bodies, but quite the reverse of this. A particle of water will rest upon water surface similarly to a solid body, as some experiments by Brewster show, and that which appears quite contrary—the water will creep up and adhere to the same bodies which resist its surface. This is quite explicable by the same principle of gelatinity that promotes and supports continuity after contact by a kind of static firmness of surface which rejects first contact. The gelatinous principle in question is evidently due to certain conditions of cohesion not present to the same extent in all liquids. The same cohesive principle is possibly maintained in ice, as is witnessed in glaciers where the ice forms stand up with remarkable rigidity, and are quite brittle if struck, yet they bend to the rocks past which they are compressed under the constant force of gravitation. The gelatinous construction of water that I propose is one cause of a special form of resistance in pipes to the free flow of water, upon a principle of fluid motion to be considered. It also gives to fluids which possess it, a special kind of rigidity by which continuity of surface is very persistent, and this is one cause of the tendency to division in motions of undulation where the surface is compressed horizontally by any small forces. These general conditions will be hereafter considered.

c. The experiment by which I tried, to investigate the relative comparative amount of gelatinity in liquids for my own satisfaction, and to endeavour to discover the cause of the extreme static rigidity of water under certain conditions, which I will discuss further on, was to cause the liquids to flow over a small bridge in a channel, and to measure the heights of the head above the bridge relative to the velocity of flow. To compare water particularly with some acknowledged viscous fluids I selected two liquids, one a varnish, a little of which placed between the fingers held them together with considerable force, and for the other linseed-oil. I selected these two liquids, oil and varnish, as I found them used previously in experiments to determine the viscosity of fluids. I constructed a small apparatus, consisting of a channel of zinc about seven-eighths of an inch square,

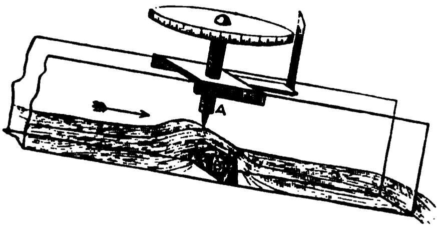

Fig. 9.—Gelatinity Apparatus.

and a foot long, which was connected with a reservoir so as to obtain a regular flow in a current of the liquid from an aperture of the width of the trough, and one-eighth of an inch high. A bridge across the channel was placed inside at one inch from the end furthest from the opening, which was made of a thin piece of zinc. This bridge stood up from the bottom of the trough a quarter of an inch. Above the bridge I placed a micrometer-screw, by which I could read to the thousandth part of an inch, and which was connected with a point to reach the surface of the liquid. I tried the two viscous fluids named, and the water, after cleaning and thoroughly drying the trough between each experiment. In the flow along the channel I found the head of water at its highest point, which was nearly over the bridge, measured by the micrometer screw taking the average of ten experiments about ·13 of an inch; the head of the highly viscous varnish measured about ·12 of an inch; the head of linseed-oil, ·11 of an inch; showing the water to be the most rigid or self-supporting, which I assume to be derived from a certain molecular polarity which produces the property of *gelatinity*. I shall be able to show in experiments further on that water in some cases acts as a colloid. In Coulomb's torsion experiments to discover the *osity* of various bodies by the resistance offered to the circular llation of a tin disk, oil was found to be *seventeen times* as viscous molecularly resistant as water. Therefore the quality of tanding up or *beading* in the above experiment, which is water than in oil, must be from a fluid property in excess *d.* The *gelatinity* or static mass rigidity of air, which I also ascribe to a weak polarity, may be shown in the slowness with which its elasticity will react in a free state. This may be seen in the following very simple experiment, by taking one of the thin tissue india-rubber balls or balloons which are blown out for toys for the amusement of children. The one I experimented upon was 9 inches in diameter. If we strike this in any oblique upward direction in quiescent air it will move against the air until the resistance of the compressed air in front equals the force of momentum given to the ball, and at this point the elastic static force of the air in the balloon and the free air will react, and the balloon will be reflected on its course; that is, it will not complete its paraboloid, in ratio to its projectile force and the action of gravitation upon it, in proportion to the quantities of resistance it receives *seriatim*, but will fall to the ground at an angle inclined to the direction from which it was projected.

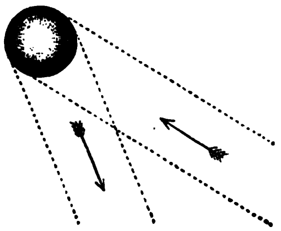
Fig. 10.—Aerial Gelatinity.

If the term *gelatinity*, or the reasons which induce me to make use of this word, should appear ridiculous to some, I wish only the property of static mass elastic rigidity of water and air to be observed as important to the elucidation of some phenomena to be hereafter considered, which gives these fluids in some cases static forces that appear very relative to homogeneous solids.

13. Remarks.—*a.* The part of this chapter that relates particularly to the static equilibrium of the molecule in a fluid was written to offer the necessary conditions for my conceptions of sound motions, in which I take the general principles of equilibrium for fluids that have been assumed to be present from Newton to Airy, only that I have substituted permanently *elastic* forces, which are assumed to act within the limits of the body of the molecule or atom, in place of *repulsive* forces, which are assumed to act without matter at indefinite distances for which these elastic forces may be considered to be motively equivalent. The fourth section of my work being now withheld for reasons stated in my preface, these matters as regards other parts of this work might have been omitted, only that they are now unavoidably mixed with the entire work, and that they give the theoretical ideas upon which

I assume a general state of molecular equilibrium may exist in a fluid. I admit at the same time that the subject is one beyond my powers of demonstration.

b. The mobility of gaseous fluids in free molecular trajectories, which I assume would be antagonistic to any theory of constant equilibrium of each individual molecule, appears to gain reasonable strength from the evidence offered in the beautiful experiments of Mr. William Crookes, of passing electrical currents through tubes or vessels exhausted, nearly as far as possible, of air. In these experiments radiant matter is projected from the negative pole, which is not only made visible by the radial direction of the rays of light, but also evident by the performances of work by the force of the radial projections. There are, nevertheless, conditions in this case which do not by any means assure us that the radiant matter observed is of the residual gas in the tube, as we find it is generally assumed to be, or even if it were this, the motivity observed might be constantly induced by electrical forces supplied directly from the battery, so that this could be scarcely imagined to be a case of *free* trajectory of the residual gaseous matter present. However, we must admit that it is an evident case of one form of projection of molecular or atomic matter, but whether it is of the residual gas in the chamber or of the matter of the negative pole is quite another question. In sparks thrown off conductors in experiments with our common frictional electrical machines, it is quite clear that pieces of the metallic conductor are projected, which inflame and produce large sparks in the air. If we reduce the pressure of the surrounding air so as to produce the ordinary exhaustion of a Geissler's tube, Mr. Crookes has found that *platinum* is then strongly projected from the negative pole, so that it darkens the glass all around it; showing that this is evidently still a *metallic projection.* But Mr. Crookes has found that in higher vacua there is no evidence of projection of the matter of the negative pole.[1] In this last case it is quite possible that the platinum itself under the nearly perfect release of pressure that these higher vacua produce, is severed into separate atoms at the instant of its projection, and that this as elastic matter (4 prop.) forms during the continuity of the electrization a perfect gas (*platinum*), and whether the gas so formed is deposited upon the posi- ole or the containing vessel, or not, will depend upon the of elastic forces due to its electrization, into its material atomic attraction for other matter present. In this instance also the constant radiation may be established from the negative pole by a system of convection currents or vortices in the vacuum chamber, by which the gas performs a definite circuit. I assume in this hypothesis that the metallic gas is invisible; but that it excites by its friction the medium of the fluid residual air or gas into which it is projected, and, in like manner, by its friction it also excites in its return current the body of the vessel in which it is contained, to cause its phosphorescence, the return current being in all cases possibly more condensed than the gas projected from the negative pole radially in the first instance. So that upon the whole I do not see evidence that this is a motive projection of the residual gas in the tube, but rather that this gas is the medium in which the projection occurs. It is reasonable to assume, nevertheless, that the projection will engender convection currents of the gas present during the atomic projection of the matter of the negative pole, and that such currents may probably return the matter projected to this pole in some cases after projection, or, if the resistance of the medium is great and condensation occurs, deposit it near this pole.

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[1] *Phil. Trans.* 1879, § 628.

c. In Mr. Crookes' earlier important experiments with light and heat in his well-known Radiometers we have all the general properties of the forces employed materially changed from conditions given above for intense electrical forces, as in the radiometer we have to deal with forms of force that exhibit much less intensity of action. For radiant heat and light, such as is active upon a radiometer, we may possibly assume a force only sufficient in these experiments to affect the equilibrium of the fluid (vacua) inclosed in the vessel in a manner similar to that which was formerly assumed for radiant heat and light by the undulatory theory, and that is now assumed for it in other cases when discussing spectroscopic matters, phosphorescence, &c. However, it appears evident that undulation would not produce the direct forward mechanical force observable in this case. But possibly the equilibrium of the molecule may be conserved if the rays of light or heat induce the formation of direct molecular *polar rays*, as I conceive may be possible in free elastic residual gas upon conditions stated in 7 prop. *h*, so that such rays may act as forces directly from the vessel to the mobile vane, with quite as great or even greater force, from the assumed elastic rigidity of the atoms forming the ray than could be assumed for the propulsive force of the free molecules present, whose weights must be conceived very small, even if they possess innate forces to be projected entirely in one direction at one time, and their velocity must be immense to give by this projection of their masses, momentum sufficient to overcome the inertia and resting friction of a relatively enormous solid body, many millions of millions of times the molecular weight of the projectiles, such as we must assume is the weight of the connected vanes of a radiometer, even assuming that a molecule or any other body could impress force and retain its momentum equally for reflection back to the sides of the vessel, with force and velocity equal to the original projection, which in this case it must be assumed to do or the whole of the projectile matter would soon rest against the vane. In this difficult case some writers appear to hold the projectile-molecule theory, or corpuscular theory as it was formerly called, for radiant matter, and the undulatory theory *also* for separate cases; this appears to me quite inconsistent, or at least so until some process of reconciliation has been offered for these separate quite distinct principles of molecular motion of radiation forces. In the assumption of the constant presence of polar forces offered above we have the conditions of a form of motion that is evident in some cases which we have not for any case of free motive propulsion of a molecule or any other body, except it is, as in the case given above *b*, induced by the constant force of electricity.

d. Upon the conditions offered above the equilibrium of fluid matter may be conserved under the impression of exterior forces that may affect its interior construction during their impression, by inducing at the time greater activity of polar forces. The molecules of fluid matter being acted upon in such cases as masses of soft iron to electrical induction, but in this case by the unknown actions of heat and light. If we assume these forces as *polarity inducing*, or strengthening forces that pervade the system of matter upon which they are impressed, and that the atoms or the molecules of bodies are symmetrical, and endowed with like polar forces, the union of such atoms or molecules in equilibrium can produce none other than a symmetrically constructed mass. This state appears also as far possible evident when by vision we can first detect the construc-
f pure matter, as for instance in the symmetrical crystalline
e of all the metals, iodine, sulphur, &c., and the same by
r certain liquids which are shown by the polariscope to
erties of crystalline bodies. So that it is only when we

lose sight of structure, by the condition of fluidity, and when the mind is left in darkness, that we can rationally *assume* symmetrical structure of matter to disappear; and it would almost appear that if matter changes its *structural laws* at this precise point, that it has been in some way created relative to the faculties of man to permit the free action of his imaginative powers.

e. For the general conditions of equilibrium in a fluid, I think that whatever may ultimately be consistently thought to be the principle of projection of radiant heat force, in any form, that the same will be applied to light, as these forces are so evidently united in their motive principles; as the conditions of similar refractions, reflections, and polarizations evidently show to my mind. Neither do I think that it is probable there are *two forms* of heat motion, that of radiation and that of conduction, as it is much simpler to suppose one mode of action for one force; *conduction* very possibly being a form of less intense *radiation,* which is restrained by resistance of the inertia of the matter affected by it. Extending this idea a little, it is also most possible that one form of motion exists for both heat and light under all conditions. If I should at any time be able to discuss my experiments on light and heat, from which I was unavoidably diverted, I will return to this matter. It would here be quite out of place to discuss the subject further than is necessary to support my propositions of the constitution of a fluid against what I imagine may be a transitory science (1880), in so far as its theoretical deductions are concerned, but not its practical uses.

f. For the equivalence of heat to mechanical force, we may assume that if heat forces act on separate atoms and molecules as proposed (4 and 5 props.), or by any means so as to increase the elastic forces of the atom or molecule by a system of movement acting contra to forces we may call chemical attractions, as I have suggested, here is possibly work that will fully represent the heat lost in its performance, whether it be in separating the millions of surfaces of the atoms of a powerfully cohesive mass of platinum, slightly against its powerful chemical cohesion, of near central contact of its atoms, equally, to the force shown in dissipating solid carbonic acid to vapour extension where chemical cohesion is represented by a small force. The greatest motive effect probable from heat in any case will be explosion, or elastic vibration, which will become finite by the influences of surrounding resistances or in new conditions of elasticity. It further appears to me that the most important physical function of heat is not to produce the palpable exterior surface forces we witness as personal temperatures; as such exterior forces may be present or not, for in this I assume that if the atomic attractions *inter se* become negative or minus quantities with respect to the elastic surface force that I propose (4 prop.) the heat force as *temperature* is entirely lost to perception, or becomes latent as it is termed. Whereas if the heat force is only sufficient to increase the elastic pressure, and not to overcome central attraction, such pressure becomes by movements producing separate frictions on every atom, active in the general expansion and outwardly possibly *vibratile* upon the elastic envelopes of the atoms or molecules, disturbed from the equilibrium of rest surrounding them, and is thus as temperature force, rendered motively free to communicate vibration as radiant heat from body to body, so long as the heated body is changing its state by either increase or decrease of heat. If the body expands, and heat force is lost as palpable temperature, the elastic forces have placed and may possibly retain, the atoms in positions in which the central attractive forces of the atom act exactly as a body placed upon an elevation above the earth. The active energy of the heat force apparently lost being conserved by a position that can restore the outward, palpable heat, by friction of *attractive precipitation* in the atom falling to its former radius of attraction. This matter, as before mentioned, has been ably discussed by Professor Balfour Stewart so far as regards the potential of molecules.

CHAPTER II.

CONDITIONS OF LIQUID SURFACE:—CAPILLARY ACTION—TENSION OF FILMS—BUBBLES—BOILING—EVAPORATION.

14. Definition. It will be convenient, before the discussion of surface forces, to define the words *Tensile* and *Extensile*, as I wish to use them in this chapter and henceforth. By *tensile* I intend a disposition of the parts of a system of matter to draw themselves together, as a stretched drum-skin does. By *extensile* I intend the reverse of this, or the disposition of the parts of a system of matter to separate and thereby to engender external pressures.

15. Equilibrium of Surface. *a.* The still surface of a liquid at a distance from any object presents to the vision a perfectly level smooth plane. The perfection of the equilibrium of a liquid surface may be demonstrated by the following simple experiment. Take a dish of clean water, the surface of which is visibly still, and prick the centre of the surface with a fine needle; this will instantly send forth a wave extending in circumference from the centre to the edge of the dish, which may be seen by surface deflections along the shadow of a window bar, or the edge of any straight object placed against the light. Upon removing the needle from the surface of the water, a similar phenomenon may be observed. I may note that in this experiment the entire point of the needle to be immersed need not exceed ·01 part of an inch in diameter, that is, occupy a space upon the surface of the water greater than ·0001 part of a circular inch. The diameter of the circular dish in which I made the experiment was 12 inches. Therefore in this case the liquid surface was thrown palpably out of equilibrium by a force of increase or decrease of area of surface by ·00007125 part of the whole, neglecting capillarity, which was possibly nearly equal in the elevation of the water about the needle to the volume of the needle immersed; the point of the needle in this case penetrating the water for a very small depth only. This puncture of the surface produced a very visible motion. It is probable that the same form of motion would occur with ·01 part of the absolute displacement, therefore $\frac{1}{100}$ part of the surface strain, but in this case we should need special optical means for its detection. By further experiment to discover the limit of smallness of displacement necessary to produce a visible disturbing influence, a glass thread of ·00025 part of an inch diameter was withdrawn from a still liquid surface. I could in this instance by attentive observation detect no surface disturbance by reflection at a distance greater than 3 inches from the point of immersion.

b. I have already considered some of the conditions upon which the rigidity of a liquid surface may depend, namely, the minus elastic mobility of the surface, and also the gelatinity as a functional quality, particularly of water (12 prop. *c*, page 36). These principles previously considered, if true, relate to the surface as a part of a general mass. The conditions I now wish particularly to follow relate to the surface as a separate system. The great resistance of the surface of water, as shown by Count Rumford's experiments, mentioned in the last proposition, assures us that we need the co-operation of every auxiliary force that may act to fully account for the great surface rigidity we observe in certain liquids, particularly in water.

Extensile Forces on Liquid Surface.

16. PROPOSITION: *That every level surface of a liquid is held in equilibrium by attractions of the surface molecules to each other, and to those beneath equally per area of the molecular surface in contact; that such equilibrium acts as a condensation upon the surface of a liquid, thereby increasing the molecular surface density.*

a. Let a liquid be constructed as proposed 8, 9, and 11 props.

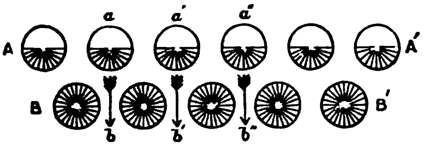

Fig. 11.—Surface Extensile Forces.

ter, then any plane surface of the liquid may be represented e of molecules AA′, Fig. 11, whose lateral attractions page 33) will be equal between every molecule, and therefore place this part of the system in lateral equilibrium, and in gravitation equilibrium also if the surface be horizontal, as before proposed.

b. To represent the action of cohesive forces by which a plane becomes *more dense*, let the plane BB′ be one of a liquid system having similar globular molecules in every direction, so that it rests in perfect equilibrium with surrounding molecular forces upwards, downwards, and laterally; then will the molecular attractions of the plane AA′ be out of equilibrium in vertical direction, as this plane will have superior attractions in proportion to the extent of molecular surface of the cohesive liquid system downward towards the plane BB′, and *no* upward attraction of cohesion. Now as the molecules AA′ fall upon the elastic interstices of the plane BB′, as shown for three places by the arrows b, b', b'', indicating the equation of the direction of the attractive molecular surface forces in the molecules a, a', a''. These attractive forces will therefore be equal to *pressures* that are constantly active between the molecules B to B′ to press between them, and thus to condense the surface of the liquid here assumed as a mobile molecular plane.

c. By the same forms of attraction as discussed above, the molecules A A′ will also by their downward attractions, which act as compressions upon the first surface of lower molecules B B′, render this lower surface also, by the molecular intrusions in the stratum below, *more dense* than any lower part of the liquid system, and this again by like compressions more dense than one still lower; the equilibrium about every molecule being at the same time preserved as far as possible. This is quite irrespective of gravitation.

d. In like manner, by the molecular conditions proposed (11 prop. page 30), and of elastic pressure proposed (10 prop. page 28), every liquid surface upon which there is exerted any pressure whatever by a motive plane, will be similar to the surface pressure of a, a', a'' intrusive in the direction b, b', b'', as in all cases the exterior molecule will be driven into or upon the interior system of molecules against the elastic resistance of the polar, or pressure positions of the molecules in the assumed porous system. Therefore the lower surface, and the lateral surfaces at any angle of a liquid contained in a vessel or pressed by a *smooth plane*, will be under *compressile strain* relative to the central equilibrium of the liquid system.

e. The demonstration of the conditions here assumed of condensation of the aerial surfaces of a liquid may be inferred in an experiment as early as Descartes,[1] and although this resembles those already offered (page 36, *b*) by Count Rumford, it may be here considered for certain particulars.

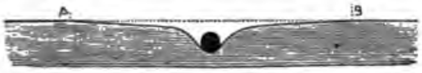

Fig. 12.—Action of Needle Floating on Water.

f. An ordinary sewing needle placed upon the surface of still water, upon which it floats in apparent contact with the water, does not break the continuity of surface or the strength of internal cohesion of the water, to follow the mass attraction of the floating needle. In this case the needle has nearly eight times the specific gravity of the water; therefore to be able to float upon it, it bends down the surface of the water surrounding itself a quantity equal to nearly eight times the bulk of the needle, so that the needle lays in a trough of the deflected surface. If we imagine in this case that the weight of the needle presses the molecules *aa′a″* in the previous diagram (Fig. 11) into the surface of the water, the elastic resistance of the surface will be increased by the pressure, as there is no space for these extra molecules without disturbing the whole surface system; at the same time the lateral liquid retains its equilibrium by an outward rounding. This experiment further gives, as before mentioned, an idea of the general elastic cohesive rigidity, or gelatinity, as I term it, of the water, which in this case offers resistance for a distance below the absolute surface to make room for the indentation in which the needle is visibly buried, as shown in the sectional illustration above, which represents the needle enlarged 2¼ diameters. The gelatinity, as a resistance in this case, may be partly derived from the continuity of like, although diminishing, intermolecular pressures to the surface pressure which acts similarly to a continuity of surface forces upon the internal water under the strain as proposed *c* above; in this manner producing a density varying inversely as the square of the radius of pressure for a certain small depth. The expansions of the lateral surfaces to the shallow formed by the needle are rendered nearly free of extensile by the curvature and continuity of cohesional contact until ilibrium of gravitation in upward hydrostatic pressure in the near parts, equals the surface resistance of the hollow surface, so that the needle, as I have found, by the elasticity of the system deflects the surface water rather less than a weight of water equivalent to the weight of the needle.

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[1] Les Météores. *Œuvres de Descartes*, vol. v. p. 187.

g. When the needle once enters the water it descends to the bottom with great velocity, from which we might conclude that the cohesive forces of the water, after the surface is once penetrated, are much weaker than at the surface. I anticipate that there is not a great difference in the general cohesion of its system, in the depth in relation to the surface, derived from differences of molecular attractions (5, 6, 8 props.) causing differences of density, except that there is more perfect equilibrium in the depth. The greater part of the visible difference in the case in question being the motion induced in the water by the needle after it has entered it; the principles of which, I will hereafter discuss in some more demonstrative phenomena; this proposition being entirely confined to the conditions of the surface in relation to the static liquid interior, the subject which I am endeavouring to investigate.

h. In the above conditions of the floating needle, if the surface of the water were already under tensile strain, as is now popularly concluded (1880), it would then be clear that the weight of the needle would immediately increase this tension, and unless the special cohesion of the surface were by some undefined cause very great the needle would immediately penetrate it. This would be illustrated by the instance generally offered of a stretched drum-skin; if this were stretched very tightly, a very moderate blow with a heavy body would break through it, but if it were loose or flabby it would resist a much greater blow, as the blow must be *plus the tension* present in the first case. In the case of a tension also the surface would remain nearly level when struck; in the case of molecular condensation which would have a tendency to extension (equivalent to looseness) the surface would be deflected by the blow of the heavy body without separation as the water surface was shown to be by the weight of the needle.

i. To observe the greatest amount of deflection of a liquid surface by a weight placed on the surface film it is necessary that the heavy body should be perfectly smooth and perfectly *clean*, as any particle of projecting matter would disturb the molecular arrangement. With distilled water, 60° Fahr., I have found that a straight polished clean steel wire with hemispherical ends, of one inch in length and

·05 of an inch in diameter, would just float with stability if undisturbed until oxidation commences. If there was the smallest particle of grease upon the wire a much less diameter only would be supported. If the same wire was dipped in acid so as to produce even slight oxidation it would also enter. The method that I have found best suited to clean the wire, after polishing, was to dip it in a saturated solution of caustic potash, to rinse it in clean water, and wipe it on a very clean linen cloth; it would then be perfectly supported. If it is not wiped it oxidizes slightly in drying. But I have found that if the same wire be afterwards touched by a greasy body, or one not perfectly clean, as for instance a hair of the head, ever so slightly, it will descend immediately upon being placed on the surface of the water. The necessity in this experiment for the polished and perfectly clean surface is that the water should at once perfectly *adhere* to the wire, and so retain as far as possible the molecular surface positions. I will make this matter more evident by another experiment further on (20 prop., *k ante*).

j. To endeavour to investigate the depth of surface that would be rendered more dense, therefore more resistant, by the action of cohesive forces in the liquid conjointly with the effects of gravitation upon a liquid surface, the last being assumed very small, I constructed a small scale-pan of microscopic glass that was of about ·01 of an inch in thickness, and 1·05 of an inch in diameter; this was suspended by three fibres of silk, and then immersed in a beaker nearly full of water, the pan was attached to a delicate scale-beam which turned distinctly with ·01 of a grain. By slowly lowering the surface of the water I found as this surface descended to the pan, that a resistance which first disturbed the equilibrium of the beam was observed at about ·08 of an inch below the surface; this resistance increased, but did not appear to equal ·01 of a grain until the pan came within about ·003 of an inch of the surface. In the above case the resistance, I believe, was largely due to the general gelatinity of the water; for if the pan of glass was moved upwards to the surface very slowly, resistance was detected with difficulty until it was very near the surface.

k. The general condensation and tendency to extensibility of a surface may possibly be better inferred by the activity at ace shown in inducing the solution of a solid in a liquid, by c pressure near the surface causing a more perfect contact re. This may be readily seen when any soluble body of long cylindrical form is partly immersed in a liquid which has power to dissolve it.

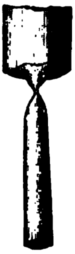

Fig. 13.

l. For this experiment I have tried successfully a cylinder of fused caustic potash, and a clear sugar-stick from a confectioner's. The cylindrical rods of the soluble bodies were cut in two by the solution after a certain time at the surface of the liquid; this effect is known to occur in vacuum, and is general in all soluble bodies. The illustration represents the form produced by the solution of caustic potash or sugar in this manner; in which it may be observed that near the surface plane of the liquid, the narrowest point of the engraving, there is a conic pointing; which I have found generally to commence at about ·08 of an inch below the surface in water. This depth may be the practical limit of surface extensibility by condensation for water, as it is about to this same depth that a surface of water may be deflected by a small heavy body resting upon it before submersion.

m. The conic pointing in the above case would appear to indicate that the surface condensation acts as a pressure from the surface downwards varying inversely as the square of the distance for a certain depth (·08 of an inch), lower than which depth, the general cohesive forces of the molecules of the liquid have not their inertia much disturbed by the surface forces; possibly by reason that their polar forces (10 prop.), although these are assumed weak, yet exceed at this distance the influence of surface forces due to attraction in the area of cohesion of the extreme surface molecules as defined *a* of this proposition.

n. In the above experiment it may be observed that there is a general conic pointing of the entire cylinder at a very small angle, as observable in the lower part of the engraving, which is from no function of surface forces, and is therefore quite independent of the principle discussed above. This general conic pointing is produced by the solution of the solid in the water being of higher specific gravity, and falling over the lower parts; the solution having less solvent power in proportion as it is saturated. This by itself would produce an entire cone extending to the bottom of the solid, and not the sudden conic pointing at about ·08 of an inch in depth in the water, as shown in the engraving.

o. The same conditions of surface extensibility by condensation appear to be evident in the extensile force with which oils or spirits spread over the surface of water with the great rapidity observed. In this case I imagine that the oil or spirit takes the position of the attracted surface molecules of the water, and that these liquid molecules by the superimposed attractive matter become now the interior of the surface system, where they fall to equilibrium as lower molecules, and become as other deeper parts of the water, except that the surface still retains a certain condensation in ratio to the differences of specific gravity of the water and the lighter fluid now above. I imagine, however, that in this case there is a certain amount of chemical action, in which the oil or spirit has strong attraction towards the critical fluid or vapour which I assume to be superimposed over the water at all times (8 prop. *e*, page 22), although this vapour is of too small a specific density to produce the same state of equilibrium as that of a denser fluid, that is of the oil or spirit mentioned above.

17. **Capillarity,** *defined as the action of a liquid which causes it to rise and hold itself up or to be depressed against a solid about the surface gravitation plane, may be attributed to five causes.* 1. *The force of extension by attraction into the liquid surface.* 2. *The attractive forces of the surface molecules seeking the greatest area of contact.* 3. *The elasticity of surface.* 4. *The adhesion of the liquid to the solid.* 5. *General cohesion of the liquid system. These conditions, although relative to each other in a certain degree, are taken separately in the following propositions.*

18. PROPOSITION: *That aerial surface forces of condensation shown in the last proposition, supported by lateral molecular pressure* (10 *prop.*), *both tending to a like extensibility, are causes of the rise of liquids against vertical solid surfaces, where the liquids are sufficiently free from cohesive intermolecular attractions to be able to touch the vertical surface at the horizontal gravitation surface plane of the liquid.*

a. If a vertical surface rising above the aerial plane of a liquid be neutral, as regards attraction for the liquid, the liquid will then rise against the solid, by the effects of molecular condensations producing extensile surface forces, as shown by the following diagrams:—

A B, Fig. 14, be an aerial surface of a liquid, and B C be the
f a solid neutral as regards its attractive forces to the liquid,
the pressure that it receives from the elasticity of the
Then, by the condensation of aerial surface (16 prop. *a*)

horizontal surface pressures will press the molecular elastic system from A towards B, and hydrostatic pressures upon the vertical solid

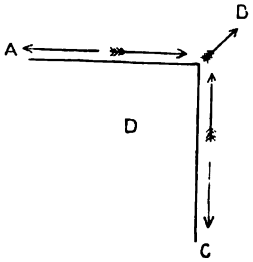

Fig. 14.—Diagram.

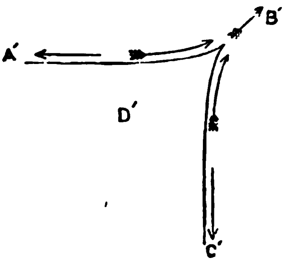

Fig. 15.—Diagram.

acting laterally will also, as hydrostatic forces, act vertically (10 prop. *c*, page 29), and will tend to press the molecular elastic system at the surface upwards to B, which will be the point of least resistance of a uniformly cohesive porous system under pressure, and the entire system by the composition of forces will be deflected in the direction of the arrow near B. This will occur although a surface rests in equilibrium (15, art. *a*) if the downward attraction of the surface molecules (16 prop.) cause a condensation by the direction of their attractions, and this condensation will produce an extension at the boundaries of a free surface.

b. The equilibrium of extensile surface forces for the inside of a flexible cubic cavity, under a state of free extensibility, may be shown exaggerated theoretically for one side at B′ in the second diagram, Fig. 15. If the vertical solid plane were continued rigid, as by upward continuation of the vertical side, B C, Fig. 14, the surface deflection would then act upwards only against this plane.

c. Under the conditions of porous molecular construction proposed (10 prop.) there can be no doubt that hydrostatic pressures will *tend* to extend and support the surface, BC, Fig. 14; but this may be otherwise partly demonstrated by pressure upon soft or hard substances proportionally to their fluidity, as defined 2 art. *b.* Thus, if we move a flat board horizontally in water with its plane normal to the direction of motion, the pressure upon the water causes it to rise upon the near forward part. If we press a long roll of butter at one end this end expands, or if we press a malleable metal the same will occur; this last instance is very important in mechanics, as the whole process of riveting depends in principle upon the malleable surface being expanded by the pressures or percussions of the blow of the hammer being active as extensile force through condensation near the point of incidence, and although the plane C B be assumed static, in this case of hydrostatic pressure, yet by the molecular porosity and elasticity of the liquid, the pressures against the plane will give the same tendency to extension as if the plane were in a small degree motive.

d. Under the conditions of this proposition, *a given liquid should rise from a level plane equally upon all bodies*, the rise depending entirely upon the molecular forces of the liquid, and not upon the solid upon which it rises; but these conditions will be modified in certain cases, as for instance if the liquid by any cause, as by the strength of its molecular cohesion, does not by its adhesion wet the solid at its aerial plane, then the same conditions of extensile surface force would cause the liquid to round outwards, that would otherwise cause it to form a hollow against a plane of resistance to the free action of its surface extensile forces. The strength of the extensile force, although small, would at all times compel a liquid to take either the round or the hollow form.

e. A liquid will, by its forces of surface extension through attraction into its mass, constantly tend to drift the matter of its surface outwards to the most free circumscribing area, where it will produce from this cause a small upward curvature against any vertical solid. But as this curvature increases, the molecules will be proportionally more nearly circumscribed by contact with others, and consequently be also more nearly in vertical equilibrium (11 prop., page 30); so that a molecule in a hollow will approximately resemble a lower molecule, there being less excess of attractive force in one direction. It is *partly* upon this principle that by the superior strength of surface molecular attractions into a level plane (16 prop.) over the more nearly circumscribed attractions of a hollow plane, that any light solid body placed upon a liquid near the edge of the containing vessel will drift from the side it receives the greatest normal pressure to that upon which it receives the least, or from the level surface to the area of greatest curvature against the solid surface of the vessel. The excess of surface curvature caused by the presence of the body lso accelerate the drifting to the most concave side, as the con-
of 20 prop. will show.

e take this proposition in conjunction with the last (16
hysical law of pressure of a liquid against a vertical

surface becomes more simplified for the rise of a liquid against a solid than the conditions required for the assumed surface tension of a level aerial plane of a liquid, and of hydrostatic pressure below this plane. As we find under the conditions now offered, the hydrostatic pressure to be a continuous process affecting the entire depth, therefore acting, although not quite equally, for all depths; the cohesive surface forces of the aerial plane acting also in the same direction in some ratio inversely proportional to their distances from the surface, thus strengthening the surface forces under conditions given in (16 prop.), so that the entire pressures are positive. Whereas, if we imagine a tension upon a level surface, this must be, as assumed by Segner, a force superior to the hydrostatic pressure at the surface plane, *or it could not act as a tension;* therefore upon a vertical plane rising from a liquid we should have, by the theory of surface tension conjointly with the conditions of hydrostatic pressure rising from depths below the surface, the pressures diminishing upwards to a *certain line* until they cease to act and become neutral at this line, whereas above this line there would be negative pressures, increasing inversely, or as minus pressures up to the aerial surface; conditions which appear to me, although supported by the theoretical deductions of many great philosophers, are too complicated to be possibly imagined to be possessed by the same physical body, in which we can distinguish no difference of parts and only small differences of conditions as active at the surface that are not general for the mass.

g. The above paragraphs relate only to the extensile pressures of an open liquid against an open vertical plane, the liquid surface being assumed of extensive area. Otherwise if the surface area were closed by contiguity of other vertical planes, or if it were surrounded by solids, then any elevation of the liquid against such solids by causes discussed above, would abstract a certain portion of the liquid from the part of the close area that would be at the time below the surface plane, and this abstraction would have a tendency to contract the capillary area, although the surface forces were acting as pressures upon its boundaries; but by the next proposition I will endeavour to show that the cohesive forces direct the surface pressures upon the vertical solids lineal to their planes, and this will limit the action of the surface extensile forces as outward pressures, particularly in very close areas.

19. PROPOSITION: *That the cohesive force, by which the molecules seek the greatest area of attractive surface* (11 prop.), *is a cause of the continuity of the rise of liquids against solids particularly in tubes and close areas, where the liquid surface is of limited extent, and supported by near resistances.*

a. Assuming extensile forces under the conditions given in the last proposition to cause a certain small elevation of a liquid against a vertical solid, the cohesive forces of the molecule seeking the greatest area of cohesive contact would *support* such elevation as a rigid system, but by its own action it would not elevate the system of a liquid from its level plane in equilibrium of repose; but conjointly the extensile and aerial cohesive forces proposed would cause this elevation. It may nevertheless be observed that these forces would act in no case otherwise *than as surface forces*, and would not be the entire causes of the maintenance of a liquid high up in a fine tube, as this will depend principally upon adhesion and mass cohesion of the liquid to the tube upon conditions to be hereafter considered.

b. The extensile force at the boundary of a liquid surface, considered in the last proposition, will account for the circumstances of deflection of a liquid against any vertical solid plane. The plane in this case may act in one of two ways according to the cohesive forces manifest at the surface of the liquid in relation to the attractive forces for the solid. If the solid body has no attraction of adhesion to the liquid, but an apparent repulsive force towards it, the liquid by its molecular cohesion will not rise against the solid, but will establish a rounded edge upon its own mass against it, as we find mercury does against glass. In this case the molecular forces of the liquid seek equilibrium by attraction to the greatest molecular area (11 prop., page 30) in their own mass conjointly with molecular surface extensile forces. The lateral supporting vessel, not entering into the system of attractive forces, is to the liquid *negative*, or as the continuity of the aerial surface to a plane of cohesive equilibrium, therefore the cohesive mass of mercury acts as the oil to the dilute alcohol in Plateau's experiment mentioned (11 prop. *c*, page 32). In the case [illegible]ercury in a tube we have outwardly a flattened nearly globular in gravitation equilibrium with equal surface extensile forces, forces producing nearly cylindrical edges in all cases in s when resting upon a level non-adhesive plane.

c. In the case of mercury in a tube, there being assumed no attraction to the solid by the continuity of attractive forces in the liquid, this is drawn down by general cohesive forces upon itself according to the conditions shown (11 prop. *b*, page 30), under such circumstances there is no necessity to assume *repulsive forces* between the liquid and the solid, as the excessive intermolecular cohesion of mercury is sufficient in itself to overcome other weaker forces for the depression, in this case observable; the glass being assumed to be quite neutral to the mercury, or even if it were ***inferiorly attractive to it*** (*negative*) relative to its own intermolecular attractions, the same would occur. If by the conditions present any liquid is unable at first by its adhesive force to touch a vertical solid at its aerial plane it will form a rounding surface.

d. If, on the other hand, the vertical surface of resistance to the extension of a liquid plane is a solid, to which the liquid is freely adherent, the force of this adhesion may be equal to that of the intermolecular forces of the liquid *per area*, or greater or less than this. We will take a case in which we may assume them greater. Then, by the superior attraction, the liquid surface in equilibrium will by its attractive forces, form a hollow circular curve inscribed in the angle of contact of the vertical surface of the solid and the horizontal surface of the liquid (11 prop., page 30), if we neglect the influence of gravitation, which would enter with a certain force into composition with the molecular surface forces proposed.

e. Now taking the above conditions, but admitting the constant action of gravitation to be sufficient to materially reduce the surface rise of a liquid system against an adhesive solid. If we assume a surface extensile by condensation, it may be equal as a supporting system, and give extensile rigidity to the surface plane of the liquid; that is, it may be inversely proportional to the depressing force of gravitation, and the molecular attractive forces of the liquid surface system simply may be manifest through the composition of all other forces present, and the area of surface be a circular concave by the free action of its molecular surface attractions alone. This would appear to be a very general condition of capillarity in small areas. Under these conditions a liquid resting against a vertical attractive surface may be theoretically satisfied by principles shown in the following diagram:—

Let A be a liquid mass, the general conditions of which will be as those proposed in (prop. 16).

f. Let B be a vertical surface having equal molecular attraction or adhesion upon the molecular system as upon the liquid at A. If we omit the action of gravitation, and assume B to be wetted by the liquid to ensure cohesion; then the surface molecules seeking the greatest area of radial forces about their centres as given in (11 prop.) would be in equilibrium at *a b c d e*, the liquid being contained within the angle produced by the lines A B by an inscribed quadrant of a circle.

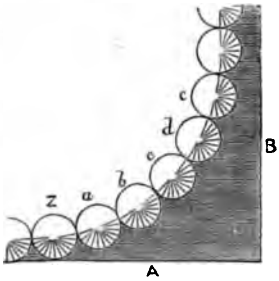

Fig. 16.—Cohesive Surface Forces.

g. If gravitation forces were active in a superior degree to surface extensibility by condensation, or resistant solids were too distant to support the general cohesive surface system, then the first molecule *a*, *held on a plane* of repose, would not be in symmetrical equilibrium with the next molecule upon the plane *z*; this molecule *z* would be therefore pressed outwards from the angle upon the plane, so that the curvature would be more nearly elliptical, and the whole system would be under elastic strain, in which the extensile strain upon the surface of the liquid would permit the support of a certain mass of liquid only in the angle by surface molecular forces against the action of gravitation, which would be active in bringing down the entire system to a hyperbolic curve.

h. If, on the other hand, we assume the point *z* to be firmly supported, this would maintain the liquid hollow with greater rigidity, or if another plane were elevated above the liquid vertically at *z*, this being opposite to the first at the same angle as A B, these angles would then conjointly maintain the liquid with greater rigidity by completing a semicircle of curvature of the liquid surface between them. It will be also seen that, as by my theory, the surface molecule always seeks the greatest area of surface contact with a certain force, and that this is best satisfied by the smallest curvature, and by this also the surface extensile forces are deflected to positions lineal with the solid against which the liquid rests; so that this extensile force becomes nearly inactive upon the solid to press it [illegible]rds. At the same time by the strength of cohesion the surface tends constantly to decrease its radius with a certain force. his principle that two free globular solids floating upon an uid, when near, are drawn together by the strength of surface cohesion in the liquid molecules seeking the greatest area of contact by internal curvature. The same also occurs when the floating bodies have attraction for the liquid inferior to the intermolecular cohesion of the liquid, where an outward rounding is established in the liquid against them, as in this case also by the depression of the rounding surface the molecule of the liquid finds the greatest area of contact in the approach of the floating solids. On the other hand, in the case of two free bodies floating on a liquid, the one adhesive to it and the other non-adhesive, the hollow liquid surface of the one coming against the rounding liquid surface of the other, the greatest area of molecular contact is then found in a plane, which, as a rigid system of surface, acts repulsively to the approach of the two bodies (18 prop.) which would upon approach cause, by the opposition of surface curvatures, a less area of molecular contact.

20. PROPOSITION: *That the cohesive forces of liquids are directly proportional to the nearness of the parts. So that upon a concave or a convex surface the cohesive forces constantly tend to make the radius of curvature less, acting with elastic surface forces equal to the strength of the cohesion of the liquid to produce this result.*

a. Referring again to Fig. 11, page 45, we may assume that the plane of surface molecules A A′ will be held in attractive positions by the plane B B′; the molecules A A′ intruding by their attractions within the plane B B′ upon their lower sides, but that in the open space above the surface A A′ there are present no such intrusions; therefore the tendency of the surface molecules would be to draw themselves together if not resisted by the attractive forces acting in the lower plane. Now, if upon the level plane these molecules exert a certain lateral attractive force towards each other, although this force be effectively neutralized by the attractions of the lower plane, yet if this plane by any cause be deflected so as to become concave, the surface molecules would then exert more lateral attraction from their nearness, and if the deflection be convex, they would exert less lateral force from their greater distances. We may further conceive that in relation to the plane below, the greater the concave deflection, the nearer the surface molecules would arrive at a state of circumferential equilibrium (11 prop.), therefore press less by their plus attractions upon the lower plane, and the more the surface was deflected in a convex form, the less would be the lateral attraction of every surface molecule about its centre, and the more it

10 Prop.

would press downwards, so that the level surface would represent a condition of cohesion under a constant strain although in equilibrium, that a greater curvature, either concave or convex, would partially release in one direction.

b. As I have assumed every molecule of a liquid system to be surrounded by elastic forces (8 prop.), the surface system of liquids must necessarily be elastic also. Further, as in cohesive elastic masses, if one plane of strain is under deflection by a force that neither increases nor decreases the general equation of forces in the mass, then the elastic compression on this plane must be somewhere compensated by an extension in another part. Thus, if we assume the attractive forces upon the molecules of a concave surface film in a capillary tube to be a self-contained system, then by the conditions given in the last proposition, if this surface attracts the molecules so as to produce a hollow with a certain force, which at the same time compresses the liquid laterally at the surface, there will be somewhere in the system an equivalent extensile force which establishes the elastic equilibrium. This matter may be roughly demonstrated by an experiment as under.

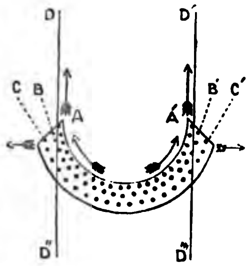

Fig. 17.
Elastic Position of Surface Forces.

c. If we take a piece of vulcanized india-rubber of the size represented in the engraving, say 1¼ inch by ¼ inch, and of any thickness, and make dots over the surface with a pen at equal distances in three lines, and now bend this into a hollow as in the engraving by a force upon the india-rubber, assumed to represent the lateral attractive surface forces of the molecules in the concave area, inducing them to make the greatest area of contact (11 prop.); then the molecules on the surface plane A A′ as they are drawn together will be condensed, and have thereby a tendency to extend upwards upon the surface D D′ at the termination of these planes, and the molecules below the surface, retaining their polar or pressure positions, will have also a tendency to distend outwards from the axis of curvature, so that on the surface molecular plane under internal curvature there will be a kind of on caused by attractive forces, but at the terminal edges of rface there will be an extension which will press the liquid o the surfaces represented by D D′. On the planes below also be an extension that will press the liquid against the tube, the extensions at the upper edges and lower planes producing an inflection of the surface plane. Therefore that the entire liquid acts as a tension to draw the sides of the tube together and rise in the tube, is that the surface molecules seeking the greatest area of contact act always with force to decrease the area and increase the curvature, at the same time the surface extension A A′, Fig. 17, being directed upwards by the cohesive surface forces lineal to the plane of the vertical surface, and the lower extension B B′ C C′ pressing matter towards the periphery of the tube to *supply* the surface extensions, but with small force only. It is important to observe in the above case, that the cohesive forces which draw the surface molecules to closer curvature, and thereby, by the elasticity of the system, cause them to *appear* to act as a tension of the surface upon the vertical solids against which they are placed, act at the same time as an *extension of this surface at its boundaries* in the same manner as indicated 18 prop. *b.* It will be seen that the theory here proposed, in which the contraction of capillary areas is the result of the elasticity of the surface forces only, is quite opposite to that of Monge, wherein the surface molecules are represented by *lintcaria,* the separate molecular tensions resembling the dragging action of the links of a free hanging chain. If a liquid could possibly rise in a tube under such surface tension, with the constant force of gravitation pulling normal to this, there would be produced a curve similar to that observable at the capillary surface in a small vertical tube; but exactly the same surface form is produced in *opposition* to gravitation when the liquid is *suspended* in a fine tube, or when it rests horizontally in one, so that the surface curvature observable in capillary action in close areas is independent of gravitation, or it may be so.

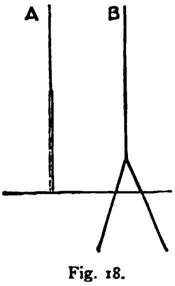

Fig. 18.
Internal Capillarity.

d. By another experiment I was able to observe the extensibility of a liquid plane immediately below the surface. If we split off a very thin scale of talc, this will be found sufficiently flexible to be folded upon itself, and if the fold is rubbed down upon a smooth surface with the thumb nail, the talc will be broken and remain quite close, so as even to possess a certain elasticity of closure. If we now cut the doubled talc with scissors, into a square of half an inch or so, leaving two projecting points at the ends of the fold, we may suspend this, by two fibres of silk, so as to leave the free edges downwards. If the talc planes are now lowered in water, upon first contact the water will instantly rise between them, and if the planes be open they will at first be drawn together, but if we continue to lower them we find that at a certain point they will open out, and as we lower them more they will open more, the effect being the same as that produced upon the dots on the india-rubber in the previous experiment, where the lower dots are opened out in the same ratio as the upper ones are closed.

e. Upon these principles every concave surface system will have an elasticity which will tend to press the liquid against the tube or close area, at a plane not distant below the surface, and at the same time the cohesive surface forces will constantly bend over the extreme surface; under these conditions the extensile pressure would increase the adhesive and cohesive forces in the same ratio upon the solid (18 and 19 props.), and the liquid would be drawn by near attractions through pressure and its increased density to the area of nearest contact by continuity of forward pressures until the elastic surface forces became in equilibrium with the resistances and the general cohesion of the system of supply; or, if the system were vertical to this strain, and to that of the resistance of friction and of gravitation conjointly; as, for instance, if a free drop of adhesive liquid were placed in a conical area, it would move towards the vertex of the cone by the forces here defined being more active in the smaller radius of surface curvature, as also by the surface density impressing the greatest lateral force, every movement at the same time by surface deflection increasing the curvature; or, if it were connected at the base of the cone with a mass of liquid, it would move towards the vertex until the liquid surface forces equalled the resistance of cohesion, friction, and gravitation combined.

f. If we now take the conditions of a *convex* liquid surface; in this case the surface molecules will be farther apart, therefore their attractions to each other will be less. But as the cohesive forces to the mass will be now further out of equilibrium with radial forces, these attractions will be proportionally stronger on the mass system beneath. Further, these outer molecules will, by the angle of con-
on those beneath, have greater *force of intrusion*, so that as the
city increases the surface extensile forces will increase also.
free aerial elastic surface forces here assumed for convex
conditions offered above, will have a certain tendency

to extensibility; and if we consider them as being impressed on a certain stratum of neutral liquid they will be active upon one side, that is, upon the upper or aerial side of the stratum taken. Suppose the extensile force upon the aerial surface by itself to be equal to a force that would increase a small circular area by ¼, then the stratum of the liquid considered would be in extensile equilibrium from this cause when its exterior superficial area exceeded its interior by ¼. It is clear that in a thin stratum this would produce a regular spherical curve of rapid curvature, if the surface stratum were free to extend in the ratios of the extensile forces present.

h. By the conditions just proposed exterior extensibility of a limited small mass would find static equilibrium at a certain outward spherical curvature; and if we were to consider the position of any lineal plane of a liquid surface at this curvature in equilibrium as equivalent to that of an elastic lineal solid body in a static position, we might then compare it with this body. For instance, taking one direction of the spherical surface of the liquid at its assumed curvature of equilibrium to be represented by a narrow semicircular steel spring of perfect flexibility, as a part of a watch-spring sufficient to form the letter C, then we should find that, to straighten out this spring to a flat plane, it would take a constant force nearly proportional to the distance moved in straightening it about its axis of curvature.

i. If a liquid surface under the conditions given above were free from lateral attractions, the extensile surface action of liquid (16 prop.), acting rapidly, would extend the upper surface considerably, and bend it over at the boundary edges of this surface. Thus if the liquid formed a thin stratum over a small part of a solid horizontal plane, the edges of such stratum would be projected forward to the front of the liquid over the area of contact upon which it rested. Under these conditions the surface extensile forces would be placed in equilibrium with the forces of adhesion of the liquid to the solid, and when the liquid became in equilibrium with the action of gravitation upon the system it would cease to move forward outwardly over the plane, but retain its beaded edge stationary. This will be the ordinary condition of a small volume of liquid resting upon a level plane, deposited without pressure, as, for instance, dew or drops of water upon glass. There is no doubt, that, by increasing the attractive force for adhesion of the liquid to the solid plane, as, for instance, by chemical action, as by the presence of an alkali spread over the glass, the circumstances may be modified, but not sufficiently so as to preclude the possibility of clear observation of the principles here shown, as we may clearly conceive from the action of a drop of water falling even upon water, near the capillary edge of a vessel, as observed by Brewster, in which case the drops roll over the surface, and do not enter it at once nor spread upon it immediately.

j. The following diagram will represent the compound conditions of surface extensibility, cohesion, and attraction in two cases. Let Fig. 19, represent the surface extension of a liquid, the cohesive forces being brought into equilibrium on a plane surface of a solid; the same conditions hold where the surface is in a tube if there is present no excess of external attraction over mass cohesion to the vertical solid, as before observed, so that the liquid cannot touch the aerial plane. Fig. 20 represents by the direction of the arrows surface extensibility, attraction, and general conditions of capillarity against a vertical attractive solid, or one at first neutral and previously wetted to produce a hollow surface flexure. The surface *extensile* forces in these illustrations are of the same values in both cases, although derived from different causes, the internal extension being caused by *crowding*, the external by *intrusion;* they are also conditions common to the same liquid: in Fig. 20 they act directly normal as a pressure upon the vertical plane, upon which they are deflected; but in Fig. 19 they act parallel to this plane, and in like manner are deflected by its adhesion; the intermolecular cohesive forces of the liquid (11 prop., page 30) being at the same time strengthened by approach. I anticipate that inflection of a liquid surface to a very small internal curvature by capillary action produces a relatively powerful extensile strain by increase of density the extreme surface; so that in this case the inflection will be at the surface, to increase the density of the liquid system, to e surface conditions as are presented by a considerable ssure upon a level liquid plane.

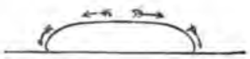

Fig. 19.—Drop on a Plane.

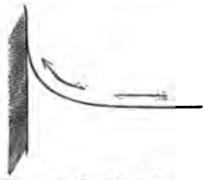

Fig. 20.—Capillary Edges.

k. The similarity of elastic deflections, therefore, of extensile forces in a curved surface under the two conditions, where a surface is made round and hollow, may be shown experimentally by raising and lowering a floating body on an open surface of water; this may be conveniently done by lifting the needle or wire described 16 prop. *f*, which will form a very interesting experiment quite in opposition to the theories generally assumed for the conditions of small dense floating bodies.

Take a polished wire as before, of an inch in length, and of about ·04 of an inch in diameter, well cleaned with potash liquor, and wiped on a clean cloth. Now carefully attach near to each end upon one side of the wire a fibre of cocoon silk by means of shellac varnish This attachment may be immediately dried if we place a hot body a short distance over it. The wire may then be suspended horizontally by the fibres to any support. Place the suspended wire in the centre of a vessel, and pour water into the vessel until it nearly reaches the wire. If we now take a syphon formed of a fine glass tube, and filled with water, and place one end of this deep into the vessel already described, and the other end in another vessel containing water; then by raising or lowering the second vessel we may very slowly raise or lower the water to or from the suspended wire. If we now carefully raise the water, the wire will make contact and float exactly as in the experiment illustrated in section, Fig. 12, page 47, the silk fibre remaining quite loose. If we now gently lower the water, the wire as it comes above the surface will draw the water up with it, as in other capillary phenomena. When the elevation is at a certain point, the same form of curvature, but inverted, will be produced at the surface as we witnessed in the depression. This is shown in the illustration, Fig. 21 above, which may be compared with Fig. 12. These operations of lifting and lowering may be repeated any number of times with care, without removing the wire from contact with the surface. This experiment is valuable in another way, in that it shows that molecular surface displacements which produce capillary

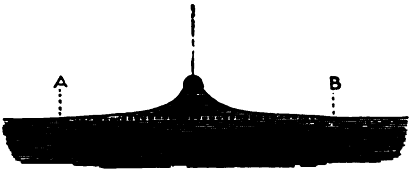

Fig. 21.—Floating Needle lifted from Water.

phenomena are not instantaneous, for if they were so it would be impossible to raise the needle above its normal contact plane upon the liquid surface.

l. Under the conditions here proposed, that of increasing the elastic rigidity of surface in a liquid upon a solid, by increasing the radius of curvature contra to the naturally extensile surface of a liquid, either by crowding or intrusion, it may at the same time be observed, that the capillary action will depend mostly upon the elasticity of the system of the liquid, which may be taken in conjunction with the strain produced by inflection. A less rigid liquid system producing less surface compression at the same curvature, which would, I anticipate, in all cases be for the same liquid, proportional to its density. Thus water at 4° Centigrade would rise higher than at any other temperature by this cause, except perhaps, at the instant of ebullition, when there are present other extensile forces yet to be considered. By the same conditions also of elastic rigidity, water will rise higher than other liquids, admitting the conditions proposed for this fluid (12 prop., page 34), the same being also evident for its support upon the surface of solids (16 prop. *d*, page 45).

m. Some theoretical deductions of Professor James Thompson of Belfast, since verified, tend to show the important law, that the melting-point of a body which expands in congelation would be lowered in temperature by pressure, while a body that contracts in congelation would have its melting-point raised by pressure. Now water is of the class of bodies that expand in congelation, and it has been since shown experimentally by Sir W. Thompson that at a pressure of 16·8 atmospheres the freezing-point of water was reduced $-0^\circ{\cdot}13$ C. M. Despretz has shown that in fine capillary tubes water may be lowered to −20 C. without freezing. If this can be taken as a measure of the surface molecular compression caused by extensile force in the inflection of elastic surface for water which prevents its freezing in the tube taken by Despretz, it would indicate that the extensile forces under these conditions are as great in the tube in question as could be relatively produced by 128 atmospheres upon a level surface, supposing the surface compression to retard freezing, and assuming the freezing to commence at the sur-
s is commonly observable. I only offer this case as one
othetical, as we are not very certain of all the conditions
or of crystallization. Crystallization of water or other

liquids appears to me to depend very much upon the facility of motions of the molecules to permit reformation to new polar positions (6 prop., page 15), and some other conditions not yet recognized by science.

21. PROPOSITION: *That surface forces of extensibility and cohesion affect the surfaces only of liquids for a very limited depth. Therefore capillary action, so far as its action at a distance below the aerial surface is concerned, is dependent upon the cohesion of the general system of the liquid and of its adhesion to the solid.*

a. The attractive forces that may be conceived active through adhesion alone would fairly represent the effects of capillary action for certain cases, but such adhesions are not easily accounted for unless they are *attractions to mass*, and in cases of capillary attraction it is possible that mass may act only as a weak force. The important experiment of M. Plateau mentioned, 11 prop. *e*, page 32, shows that mass acts as a *very weak force* for the cohesion of liquids, if it acts at all, as the globe of oil in the case given in the paragraph referred to is not deformed by a heavy iron ring, which it evidently would be under any form of active mass attraction in the liquid about the solid. Therefore I suppose that the rise in capillary tubes is almost entirely due to cohesion (11 and 19 props.) and surface extensibility (16 prop., page 45), previously proposed, with such components of elasticity as are produced by inflexion considered in the last proposition. The whole of these forces being assumed to act contra to gravitation in the elevation of a vertical capillary system, but I assume that the *maintenance of a tall volume of the liquid* in a close area above gravitation equilibrium is largely due to the adhesional and cohesional forces now proposed, as the surface force is active only within the liquid at a position very near the aerial plane.

b. In the case of glass and water we have evidence that the adhesion of the water to the glass after intimate contact is a superior force to the intermolecular cohesion of the water, as, in the separation of a clean disk of glass from the surface of water, the line of fracture or separation is always at a distance from the surface of the glass; this distance being uniformly at about ·12 of an inch in the water below the line of contact. It must be conceived that this is within the *radius of attraction* of the glass from some cause, as the liquid system being homogeneous must evidently break in the weakest plane, or that which receives the greatest gravitation strain upon its cohesive system. Further, one sheet of glass will lift another below water, and a sheet of glass wetted with water will retain a certain stratum of water upon it even if placed in a vertical position, without the water flowing down, which is evidence of the intimate cohesion of the thin surface of water being superior to the force of gravitation upon it.

c. Newton has briefly discussed capillary action, and has given the ratio existing for distance between two vertical plates of glass to the height that the water will rise between them, in which he says this[1] "*will be reciprocally proportional to the distance very nearly; for the attractive force of the glasses is the same whether the distance between them be greater or less, and the weight of water drawn up is the same if the height be reciprocally proportional to the distance.*" This is perfectly consistent with the observed action of adhesive forces that are active from some cause nearly inversely proportional to the square of the distance within a very limited space. Newton further shows that the height that water will rise in a slender glass pipe will be reciprocally proportional to the diameter of the pipe, and will equal the height to which it rises between two plates of glass, if the semidiameter of the interior of the pipe be equal to the distance between the plates. These conditions appear to be quite true and clearly definable as components of adhesional forces for the fixed position of the liquid after contact or elevation within the tube. Upon the certainty of these conditions it appears to me probable that the adhesional forces in liquids most probably extend beyond the first line of contact by proportionally strengthening the cohesive forces of the liquid molecules by attractive forces *inversely proportional to the square of the distance from the surface of contact, and which may be taken as a whole or by consecutive attractions with like effects.* These adhesional forces are probably derived from the intermolecular pressures caused by the pressure of the surface of the solid against the liquid. According to conditions of 10 prop. *c*, page 29, by which the hydrostatic pressure upon the surface of a liquid resting against a solid causes intermolecular intrusions of the same kind as proposed, 16 prop. *a*, page 45, for aerial surfaces; these intermolecular intrusions acting by certain amount of suppression of elastic intermolecular space, ise the molecular attractions, and thereby practically extend rces of cohesion to the solid, as adhesions which are found ely as the square of the distance for a small distance, ·14 of an inch as offered experimentally for surface 1 16 prop. *k*, which would be active for ·28 between two in a tube of this internal diameter.

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[1] *Opticks*, 31 Query.

ught that capillary action is better explained by mole- ons sensible only in insensible distances, first proposed, I Ionge, and supported by Young and Laplace. I do not helps the matter. It is no doubt nearly true as regards n *within* the solid against which a liquid rests; but is not true to experiment in the liquid itself. If the glass for water were active *within the water* at insensible , the disk of glass just mentioned, as being lifted from water, would not be affected by the adhesion of the uld separate the water so as to leave only an *insensible vater upon it*, as it is quite clear that, in the assumed ie adhesive system of the entire water, near and at a dis- ie solid, or of an assumed consecutive cohesion, sensible sible distances in all parts, the glass would not lift *any ravitating matter greater than the extent of the surface the glass from all causes*, and would therefore separate iid at its highest plane, so that if the glass were wetted of attraction would be so small as to be imperceptible.

liquid indefinitely when it is placed upon a level surface, where there is present no gravitation force to resist this extension such as we find present in the case of a vertical tube; this it should certainly do if the capillary action were due to its attraction to the solid simply at its nearest plane; for upon the level plane it would act under no restraint from gravitation, but be aided by it, and the principle of its first attraction would proceed indefinitely over the plane until the liquid was equally wetted by a very thin stratum. Whereas the spread of a liquid upon a level plane is quite different, if there is no chemical action, the terminal edge is in no case a thin molecular stratum, as it is observed to be universally under capillary elevation (20 prop. *i*).

g. The conditions of tensibility assumed for a liquid, as already discussed, and represented by a stretched drum-skin, have been sometimes taken from the conditions of films, which can scarcely be relative to the surfaces of masses, as the position of the attractive matter, therefore of the attractive forces, of the molecules are upon a different plane; those in films being placed lineal to the attractive matter, those in masses normal to it. If we assume capillary surface simply tensile as the film would be, then it would be clear that such tension would be pulling the liquid towards the centre of a capillary tube, and thereby lower the liquid by decreasing the possible attractive forces which would otherwise exist naturally against the solid surface of the tube, together with the hydrostatic pressures present.

22. PROPOSITION: *That the rise of a liquid against the surface of an adherent solid is proportional to the support the elevated liquid finds in the closeness of the parts of the contiguous solid and the liquid cohesion conjointly.*

a. By conditions proposed, a convex surface of a liquid may find equilibrium in curvature (20 prop. *h*). If a liquid rise against a concave solid the exterior surface of the liquid will by its convexity be approaching equilibrium, and be thereby of more open structure than if it rested against a concave surface, which I have already assumed will be in a state of lateral extension. Under these conditions a liquid resting in a concave surface will be more free from lateral ure to move upwards; for although its radial compressions will ngthened by the *intrusive pressures* the lateral or *circumferensures* of the molecules will be less. Therefore there will be dom for elevation by the general conditions of capillary ıe rise of a liquid against a concave solid than against a

proposition, page 30, the particles of a liquid seek the
a of contact. By 16 proposition, page 45, the surface
xert efforts of intrusion which make the surface extensile.
osition a solid may act by adhesion with limited force
 liquid in its attraction to the surface of the molecule.
e a surface extensile, as I propose, the liquid will by this
its attractive forces strengthened to rise against a solid,
present a greater surrounding area of attraction to the
ecules than these molecules possessed in their position
quilibrium upon the liquid surface. Further, the mole-
se proportionally to the extent of attracting surface that
ses lifts them upwards. Now, if we take a solid body of
itely small cylindrical area, and place this vertically in
his case, as the molecules rise against the small cylinder
have to be placed in such a form as to be compelled to
utline of the cylinder at the liquid surface. It is clear
that the *surfaces of contact* (11 prop.) per area of each
uld be less than when the molecules rested in lateral
in the plane of repose. Therefore by the same prin-
prop. the surface liquid would not rise at all, as the mole-

will act inversely by its support receding radially from the convex rigid area.

e. To investigate the general principles of the combined effects of open capillary attraction into area of contact I took as a first experiment a clean sharp razor. This I fixed in such a manner that the cutting edge was quite vertical to a liquid surface, the razor being immersed sufficiently to ensure general contact for the portion below the surface. After I had entirely immersed the razor in the liquid, and agitated it to ensure contact, I then dried it and found upon second immersion in the liquid at the position given for the experiment, that from the very small amount of surface oxidation now formed, adherence was almost instantaneous and perfect.

f. The liquid that I found best adapted for this experiment was pure water, to which one half per cent of acetic acid was added to give attractive force. This acidulated water made a permanent dark line of oxide to the extent of capillary attraction upon the surface. The rise upon the sharp edge was only just visible above the liquid surface plane. The general elevation was as in the diagram below, the water line being shown at A B, the rise being greater in the hollow of the razor, falling at the angle which turned for the back, and rising in the centre of the curvature at the back; this last rise appears to be due to a mass attraction. I consider that there was, however, a certain amount of chemical action which increased the capillary attraction and gave a general compensation of forces in all the curves; but the effect of capillarity was roughly indicated for vertical curvature.

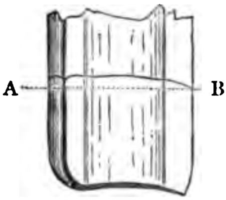

Fig. 22.
Capillarity upon a Razor.

g. To trace more particularly the effect of curvature and extent of near surface, I drew out with a spirit-lamp from a small glass tube, fine tubes of various sizes, until I had a good assortment. Selecting four of these by measuring them with a micrometer under the microscope, I obtained tubes from parts of longer ones which appeared nder the microscope by the reading of a micrometer very approxitely in series ·00025, ·0005, ·01, and ·1 of an inch in external ters. These I fixed vertically by sealing-wax at about one inch n the edge of a card which was about five inches long by two le. Taking a pan of clear water at a temperature of about ade I supported the card so that the ends of the glass tubes were each about half an inch under the surface of the water. Seeing by a hand-magnifier that they were thoroughly wetted on their surfaces, I left them in the water for about twenty-four hours.

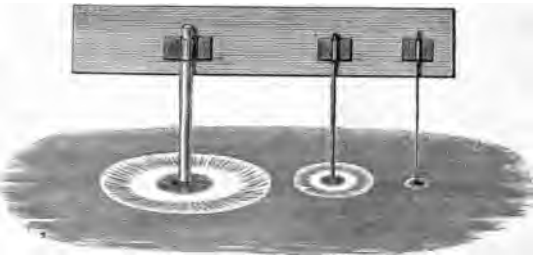

Fig. 23.—Capillary Surface Reflections.

The following day, on raising the glass tubes, I found them equally wetted. They were now left immersed about a quarter of an inch only in the water. In an hour's time, when the upper parts were quite dry, I read off the capillary action to the exterior of the tubes in the following manner:—

h. Placing my eye at an angle of about 15 degrees to the surface of the water, I obtained a bright reflection from the vertical image of a solid straight-edge which showed clearly the elevated water near the tubes; the reflections appeared as rings of light around the glass tubes. By a little adjustment of the eye according to the direction of the light, a point could be found where the first part of the palpable angle of deflection rose from the smooth liquid surface. By placing a transparent opal glass rule above this, the reflection of the rule was thrown into the water, and the position of the lines of the first elevation of the water were measured off by the greatest diameter of the reflected light, approximately. These measurements were as follows:—

	inch.	inch.	inch.	inch.
Exterior diameter of glass tube,	·1	·01	·0005	·00025
Diameter of area of deflected surface,	·89	·5	·21	·15

i. The glass tubes under the microscope all presented a bore of about one-third of their entire diameter. The hyperbolic curve of flexure of the water surface against the tube was approximately proportional to the dimensions of it, as theory demands for attractive forces; the heights would therefore be relative to the breadths of deflection; giving thereby the elevating force of the system.

j. With a solid glass rod of ·25 of an inch in diameter the surface deflection extended ·45 of an inch from the surface. I measured this by the reflection of a vertical window bar by moving the eye until the reflection from the water ceased to have its outline indented by the capillary deflection near the solid glass rod. The greatest extent of surface deflection by a plain solid that I have been able to produce, was ·47 of an inch nearly.

k. In considering the entire attraction from all causes I found that with a larger tube, as one ·5 of an inch in diameter, I produced a ring of only slight excess of diameter over one ·1 of an inch, plus the difference of diameters, so that beyond ·1 of an inch diameter of a mass, there would appear to be but little measurable difference of capillary force from curvature.

l. To examine concave surfaces the following was tried for me by a friend, as I had not time. Four tubes were selected, and carefully ground away to nearly half their diameters, leaving about 185° of the internal circumference as nearly as could be measured. The ground surface was afterwards polished. With these sections of tubes fixed on a card in the manner described for the previous experiment, the result showed the rise according to the following table measured approximately in fractions of inches:—

Fig. 24.—Section enlarged.

Diameter of half tubes.		Capillary rise.	
Outside.	Inside.	Outside tube.	Inside tube.
·210	·152	·060	·155
·160	·105	·057	·255
·110	·069	·054	·310
·072	·030	·052	·415

m. In making two of these tubes of equal size for experiment it was found that there was a slight variation in the rise of water from the above; but the difference was too small to need a repetition of the experiments to ensure the general principles, which is my desire alone to follow in this treatise, and not the investigation of quantities.

By the above experiments we may conclude that the adhesive including capillary action, evidently act in every direction int upon a solid surface equally. This may also be demon- he following experiment:—Cement two clean glass plates th an intervening slip of thin glass between them along edges as shown above, A; leaving the opposite edges near f the plates be now thoroughly wetted with water con-

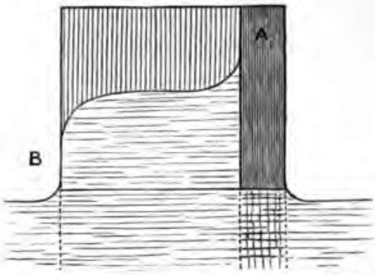

Fig. 25.—Capillary against a Supported and an Open Plane.

tle alkali and then placed erect in the water the water ated against the surface of the thin slip of glass A in rsely equal exactly to the depression at the open edge B.

e surface strain producing drops in small jets.

OSITION: *That the extensile force active within a plane rial liquid surface, is a cause of the separation of a fine n into drops.*

tensile surface force deflect the issue outwards, and enlarge the stream as shown at C C′ in the ratio of circumferential surface expansion. This expansion will take place also longitudinally upon the direct lines of the stream, contra to the central cohesive forces of the jet here assumed to be small, and by expansion the stream will divide into separate units or systems in equilibrium, as drops; the direction of the forces being as shown by arrows in the diagram above. In the engraving the projection is shown downwards; exactly the same effect will be produced if it is projected upwards, so that this action is independent of gravity.

c. If we could assume, on the other hand, that an aerial, lineal, or convex surface of a liquid in mass were *tensile*, the stream at issue should have a force of contraction exactly opposite to the above; therefore by this immediate contraction a cylinder of less diameter than the size of the hole would issue. Further, the stream would continue in the same form as at its issue by the constancy of the tensile strain upon it supporting its general cohesion; this same force would also tend to constantly decrease the cylindrical circumference of the stream, and keep up the continuity of the same form in any small free cylindrical jet projected downwards, and thereby prevent division, so that with a tensile strain, the water would fall to the ground in thread-like masses instead of drops.

d. By the principles of extensile surface strain, which I assume to actually exist on the surface of plane or convex masses of liquids, we may conclude, that if this force were active upon a fine falling liquid stream, that the central cohesion of its mass would be broken if the longitudinal extensile surface force were sufficient to overcome its cohesion in a very small unit of time. In this case, by the expansion, every free part of the falling liquid would be projected separately in drops, as soon as its central cohesive force could be released from surface strain. Further, every jet under any conditions in falling or rising would have this tendency to separate into drops.

e. The value of the extensile surface force of the stream in its power to break the mass cohesion of a jet would depend upon the size of the jet, for it is quite certain that if we assume the cohesion of the liquid as a certain force, and the surface extensibility as er force; then as the surface of a body constantly increases rse ratio to its decrease of mass, or in proportion as the dia- creases; there will be a certain size of jet wherein the surface rce is in equation with the cohesive force, and for smaller

is the surface extensile force will be the *greater*, so that
nust be separated by this, if the force acts immediately.
ie streams from this cause will be detached into drops
on issue; and although we may imagine that the cylin-
will have extensile surface forces active upon it, every-
it will, by the extensile force present, be in such a state
equilibrium upon the whole surface of the cylinder, that
disturbing cause in the air or otherwise would tend to
urface forces to equilibrium, which could only be found
uid body in the globular form, or in free drops. In this
erfalls from great heights, as the Staubach Falls in
(1000 feet), have their waters divided into spray of fine
the stream reaches the bottom of the precipice from
rojected. The same also occurs in principle in the pro-
ater in large fountains, as at the Crystal Palace, where
issue from a pipe of apparently 2 to 3 inches diameter
fine spray in about 50 feet of projection.

conditions offered (16 prop. *b*, page 46), the extensile
s of cohesion will be in equilibrium (11 prop., page 30)
xternal curvature of a cohesive system equals the
of these forces to distend (20 prop. *b*) by molecular
n the central cohesion, so that at a certain size a drop

tensile or extensile, if the cohesive forces exceed the surface forces, which they in all cases appear to do. In the spheroidal state of water upon a hot plate I anticipate that the surface must be undoubtedly expanded by the heat, and can be withheld by nothing except the cohesive force of the liquid system, which is surrounded possibly, by a surface expansion into elastic critical surface fluid, the dryness, and therefore the non-conducting power of which, and the presence of surrounding vapour prevents excessive evaporation.

Motive continuity of surface extensile strains in surface movements upon liquids.

24. PROPOSITION: *That in the extensile surface of a liquid, disturbances by compression upon the surface that produce a greater area, will be persistent in extensions over the surface in proportion to the force of extensibility of the free surface.*

a. As a free liquid surface under the action of gravitation is found to be a level plane, every possible disturbance will necessarily increase the area of this plane.

b. We are indebted to the valuable researches of Mr. J. Scott Russell[1] for the very important discovery, that a protuberance raised upon a surface of water in a parallel channel by any means, will go forward in the direction of its original impulsion for great distances, even for miles, without greater decrease of altitude than can readily be attributed to molecular friction of a moving system, so that the surface curvature once produced is maintained with considerable force. In this matter we may conclude that *if the surface force were extensile it would support a protuberant wave. If it were tensile the tension would constantly be active in lowering the wave.* I wish to call attention to this fact only upon principles of surface tensibility. I will return to the consideration of the general principles of this nearly frictionless wave further on.

c. By another interesting experiment offered by Mr. J. Scott Russell (page 377 of the same reports) a wire a sixteenth of an inch in diameter is inserted for a very short distance in the still surface of water in a large tank. The wire is then moved forward with a velocity of about one foot per second. It is found that the sur-
of the water in front of the wire is rippled up in small waves,
h 12 to 20 may be distinctly counted; whereas, following the

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[1] *British Association Reports*, 1844, page 319.

direction of the wire, the water is nearly still, or only affected by very faint undulations. The rippling or crumpling up of the surface extends to about three inches in front of the moving wire. It would appear to be necessary in this case that the water must possess an extensile surface force to form this undulatory surface in front of the direction of motion under the impression of the small moving body at so great a relative distance from it. If the surface were tensile, it is presumable that it would open to the impression of the small moving body, and the distance ruffled in front would be very small. We may conclude that as soon as the surface is ruffled in small undulations it loses a great part of its rigidity, and that this is the cause that the extensile compressions can be detected for three inches only before the moving body. If it were not for this crumpling it is presumable that from the constancy of extensile strain its rigidity would be made evident for a great distance. I will return to this matter further on when I take into consideration the phenomena of waves.

Tensile forces in liquid films.

25. PROPOSITION: *That a free film of a liquid as a free homogeneous cohesive body will be under tensile strain in proportion to the strength of attractive forces of its molecules that causes its cohesion and by its adhesion to surrounding areas of attraction.*

a. Let *a a'*, Fig. 27, represent a film, which, for the principle of the proposition, may be a single plane of molecules, and let this plane be distended between two solid bodies. Then will the cohesive forces in the film be attractive centre to centre diametrically, and the film will be in *tensile equilibrium.*

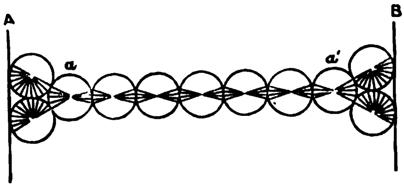

Fig. 27.—Diagram Tensile Forces in Films.

b. Let the terminations of the film, *a* and *a'*, each rest upon two molecules in the manner shown in the figure; then the area of attraction of these molecules will be greater than the area of attraction between any two molecules of the film, and these will by their forces pull the film to the planes A and B, or exert constant *tensile strains* upon the film by principles discussed (11 prop., page 30) in the attractive forces of every molecule endeavouring to find the greatest possible area of surface attraction.

c. If we imagine the film to be of two or more series of molecules, as shown in the diagram below, Fig. 28, then will the same amount of tension be established as that just discussed, as the attractions about the exterior planes will be equal and the medial planes will be neutral. It is presumable that in every film there are many hundreds or thousands of planes. The attachments also will extend to a cone of such molecules of many times the width of the film, and resemble the attachment of the molecules shown Fig. 27 upon the planes A B. The general conditions of the force of tension of a film of water may be discovered by the following simple experiment.

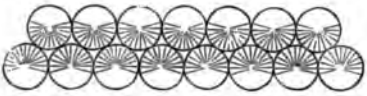

Fig. 28.—Diagram Films.

d. Project a small jet of water into the air and ascertain the force of its projection by the extent of its trajectory against the constant force of gravitation acting upon it and the resistance of the air. Again, project the jet in such a manner that it may adhere to a surface of water in contact with it, so that it carries up a film of water with it. The film will now under this condition suffer such restraint to its trajectory as its tensile force will cause, approximately.

e. The apparatus I have used for this experiment is constructed as follows:—A supply can of water is placed at some fixed elevation; a small caoutchouc tube is connected to the can to supply a jet. The tube is of about ·25 of an inch in diameter. In the free end of the caoutchouc tube a piece of glass tube of the internal diameter of the outer tube is fixed. The glass tube is drawn off to a fine point of about ·025 of an inch internal diameter. The can of water [illegible] adjusted to various heights by a cord and pulley above the jet, which is placed just within the surface of water in a trough. The tube which produces the jet is held down to a light frame under r surface, so that it can be tipped to any inclination, and by of an adjusting screw, if so tipped, it can be restored to sition afterwards by the weight of the frame. This t is shown in the figure below, A being the tipping part djusting screw. With this apparatus the orifice of the ı be at first set to an angle to the horizon with its point or at the water surface, and when the water is flowing it will project a stream entirely above the surface. But

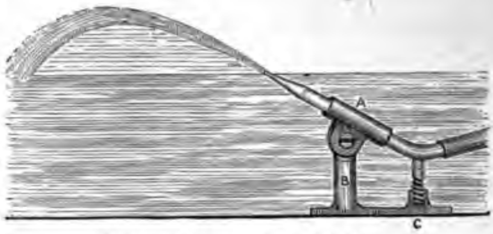

Fig. 29.—Apparatus to Project Films.

ted below the surface, and again brought to the same st, it will carry up with it a film of water which will its cohesive force the projection of the stream. I found paratus, by keeping the point of the jet at a constant small the water surface, that is at about ·02 of an inch, that if placed erect no film could be formed; that if the jet were great angle to the horizon a film would be formed, if the iall; but at a very low angle the force might be very great.

carrying up a film of water, height of the projection ·12 of an inch, distance 3 inches as nearly as could be measured.

In these experiments the cohesion of the film being equal to the restraint of the projection into the area of the film; the entire force of restraint of the film will vary as the difference of forces necessary to describe the greater over the lesser range.

i. The film in these cases is quite persistent, and remains as long as the water in the reservoir is kept at the same height. Perhaps the above by calculations, with further corrections for collateral conditions, may give an approximate value of the tension of a film of water; as the force of trajectory is easily computed in equation with the restraint the jet suffers by the film *per area.* It is possible that an approximate value of the cohesive force of the water *in mass* might be ascertained by the restraint to projection exerted, into the transverse area of the film, in the experiments described above, if the film could be rendered motionless, so that it could receive no supply of liquid from the distension of the surface upon which it was projected. In these experiments, however, the film will be found to be in revolution by principles of motion to be hereafter discussed, and these revolutions will of themselves produce a strain upon it in the plane of its distension, and at the same time by the tangential force of the revolution, withhold the liquid surface upon which the projection is made, so that the cohesive forces ascertained by the means I propose will be only approximate.

j. I have endeavoured by tracing all the conditions in my power, to obtain an index of the cohesive force of water by the means indicated above. My results gave me the cohesive force equal to a cohesion *per area* that would support a hanging column of water of 17 inches in depth. I have, however, reason to suppose that this even may be too low an estimate; but I withhold all details, as I have no doubt such a proposition would appear extravagant, when we find the cohesive force of this fluid is generally estimated at about $\frac{1}{7}$ inch only by some, and by others, on the dynamic theory, that there is no cohesion whatever in fluids, but the reverse of this, separative action.

Extensile surface force of a liquid under evaporation.

PROPOSITION: *That the surface of a liquid under evapora- this cause constantly extensile, in proportion to the rate of*

ll known, that water either under the pressure of a gas

vacuum of an exhausted receiver, is constantly under-
ration at its surface, until the gas becomes saturated,
us space becomes charged with an amount of vapour,
force of which, by itself, produces a certain surface
is evaporation or vapour force being in known ratio
erature. When the water surface is free the vapour
ed at its immediate surface plane may be conceived to
perior stratum of a more attenuated molecular form of
g above the liquid proper, which may be necessary to
osed above the water for it to remain quiescently in static
as a permanent liquid, on conditions of surface equili-
ed out (16 prop., page 45).

the above conditions we may imagine that the surface
must be by some means endowed with a force that can
expanded fluid which we term a vapour. It is also
t this force is partly communicated to the liquid by the
as that rests above it before a superficial vapour force
fficient to stop excessive evaporation. Under any condi-
our being in a more extended state than a liquid, as its
ht clearly indicates, must at the *instant of its formation*
liquid surface by any cause, be endowed with a force of
ich will at first be *at or within the liquid surface*, that is,
from it and therefore it must expand *in or at* this first

that exist at this surface, which is demonstrated by the chemical and physical differences which the two positions in and on the liquid indicate. Thus alcohol, ethers, and essential oils as turpentine, spread instantly over the surface, whereas they unite very slowly, or not at all, with the mass when entirely submerged. I have found it convenient to consider this surface molecular system, which I assume to be equivalent to the critical fluid of Andrews, as separate from the liquid system proper, in which the surface molecule forms a part of the liquid mass, as I find a liquid has molecular cohesive forces quite independent of any superimposed vapour systems, as shown for fluid glass (11 prop. *j*, page 34), as also in M. Plateau's experiment of oil in dilute alcohol already discussed; but I anticipate that the critical surface fluid prevents at all times the immediate evaporation of the liquid by constantly exerting a certain pressure upon the surface molecules to support its equilibrium, so that the conditions are not quite according to those defined, 16 prop. *b*, page 46.

d. The entire expansion of a liquid surface may possibly be seen most clearly when the liquid is in a state of violent evaporation, as in boiling. In this state the heat forces, whatever they may be, which cause the expansion of the water into vapour, will be most active, and the surface expansion, if real, most direct. At the same time any possible expansion of the surface will be withheld by the general mass cohesion of the liquid beneath, and by the air or vapour or critical fluid pressure above, with a force in proportion to the cohesion of the liquid at the temperature at which it is taken, from all causes; so that the outward or visible surface expansion can only occur when the extensile force of the surface exceeds the cohesive force, together with the exterior pressure upon it. In boiling, the superimposed pressure is assumed less than the tenacity of the cohesion of the liquid beneath, for any minute surface depth of the liquid that we may term a *film*. This film will therefore, under the strain of distension, be so far out of equilibrium in the system, that it will be vaulted upwards into the less resistant media above at the instant that the expansive surface force overcomes the cohesion to the mass beneath. *And the vault or bubble so formed will represent at the instant of its formation as a free surface, the ratio of e expansion of the extensile force of a liquid surface in contact vapour, from all causes.* At the extreme temperature of he vault or bubble when formed will break, as soon as permits the expansive force to overcome its mass

uch breaking being generally rapidly accelerated by the
ir which again accumulates from the surface beneath.
case of heat applied to the bottom of a vessel of liquid,
vapour is rapidly formed upon the lower surface, at
her temperature than the superimposed liquid above,
ubble of vapour, itself created by surface extension at
the vessel, will, by its specific density being less than that
l in which it is set free, have an upward projectile force.
efore, when it reaches the surface, aid in projecting a
t or bubble, or it will otherwise, by a kind of intrusion
xtensile surface, expand as the nucleus of a bubble.
urface temperature be lower than the boiling-point, that
face is not in a state of distension sufficient to overcome
force of the general liquid beneath, the small rising
simply burst at the surface or rest upon it, or even be
f the surface temperature is much lower.
case of water being heated as uniformly as possible,
aults may be seen to rise from the upper surface only,
greater number will receive the first impulse of projec-
smaller bubble rising from the lower or lateral heated
before proposed. This principle will be easily conceived
y, as the upper surface extensile force will be lineal

equilibrium of rest may be very great, but under any force that causes at first a slight flexure, it will lose all its rigidity and give way, so that afterwards a less force may bend the rod to considerable curvature, as the bubble of the surface film may be assumed to be bent immediately after its release.

j. In this manner, if a liquid of prescribed area, supported by surrounding solids, is kept perfectly still by shading it from motion and falling particles, its critical vapour resting quiescently in equilibrium as perfectly as possible, may have heat applied to raise its temperature far above the ordinary boiling-point before surface-vaulting or boiling will commence, or such an amount of evaporation as generally accompanies ebullition. In the case of pure water that has been deprived of air, some experiments of Donny have proved that this liquid may be raised to a temperature of 135° C. without ebullition. That this is particularly due to the quiescent state of the surface may be seen in that water thus heated will by a touch of a needle, a particle of dust, or any other small disturbing cause be thrown into a violent state of agitation, which will not again cease until the temperature falls to 100° C. This fact shows that it is ready to *distend* at any instant if the continuity of surface presents at any point a greater convexity than the level plane; which it must do in certain local positions by any disturbance caused by intrusion of other matter at its surface.

k. Under the above conditions there will be two temperatures for boiling, one in which the surface is agitated by rising bubbles or by mechanical means, and another in which the liquid uniformly or surface-heated, boils by vaulting of the quiescent surface, when the distention overcomes the molecular cohesion. As this quiescence can only be relative to exterior disturbing causes which are always present in a greater or less degree in a moving atmosphere, the last temperature is probably very high and cannot be discovered.

l. Capillary tubes placed in a bath of water so as to be gradually heated, will elevate less water as the temperature rises, probably from the minus elastic force of the critical fluid that rests on the aqueous surface; but at the instant of boiling the expansile surface force overcomes this resistance and the water darts up the tube.

l extension of surface in the boiling of liquids.

OPOSITION: *That the vaulting of a liquid plane to form a*
le will be in instant equilibrium when the exterior surface

equals the duplicate or triplicate or quadruplicate area of
rom which it is projected.

conditions offered 16 prop. page 45, a liquid surface
quilibrium when its molecules are in regular stratified
sessing in this state of equilibrium surface extensile
n elevating force act upon such a plane, equilibrium
stored unless the plane be expanded to quite double its
a, so that the one plane of molecules is intruded into the
of the other, or, if the elevating force be greater, a tripli-
y possibly be produced, or a quadruplicate, that is, a free
this last case a duplicate surface may be produced by
sion of the nearest molecule beneath, and the duplicate
by another like intrusion to form a free bubble, whereas
e area would cause a general frictional derangement of
hence it appears that duplication is the most general

he principles offered above, a bubble at its elevation will
end an arc of about 180 degrees, the number of aerial
the vault being the duplicate of those upon the level
he liquid, or the bubble may subtend, as I find by cal-
arc of 218° 56′ 30″, the superficial area being the tripli-

using the efforts of its attractive forces to find equilibrium of radial attraction, therefore the edge of the bubble when it rests on the plane will be elevated, and the centre of the included area will be depressed. There will be a constant tensile strain over the bubble by its union to denser matter, as shown 25 prop. *a*, and this will tend to depress it; but as this lowering will cause greater compression on the air included, it will generally reduce the film in thickness only, until it breaks.

d. The following diagram will show the character of bubbles, of

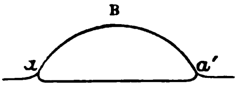

Fig. 31.

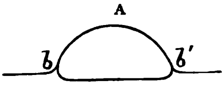

Fig. 32.

instant static equilibrium, Fig. 32, and, after action, of extreme tensile strain, Fig. 31, by the action of gravitation on the plane on which it rests for very large bubbles; this form, however, is not general.

e. A bubble may rest in static equilibrium on the surface of a quiescent liquid if there is sufficient vapour force above it to prevent evaporation, and if it be constructed from the surface film which it covers, as in this case, the positions of molecules *a a'* and *b b'* of the diagrams above will support by their attractions the circumscribed area of capillarity.

f. In water and most fluids the bubbles assume instantly the duplicate area figure. In the agitation of cold fluids this is also general, but very large bubbles, that have sometimes little or no vapour support, become occasionally extended as shown in Fig. 31.

g. The boiling of liquids as before proposed occurs when the vapour force between the molecules of the liquid proper exceeds the vapour force superimposed upon the liquid surface. So that if we increase the vapour pressure above a liquid, its temperature may be increased in like ratio without boiling.

h. In blowing soap-bubbles it appears that these may be increased to indefinite size by the internal pressure of the breath, so that these bubbles do not follow the conditions of this proposition, *a.* In these bubbles the water is combined with a viscid substance which permits nated displacements that under the tensile strain are in rapid in which they take interlaced diffusional forms, the con- which may be observed in the polariscope by the colours oduced by light passing through them.

ndependent of the mode of construction of a bubble a like liquid plane, it will possess generally a duplicate plane beneath, as this is a figure of equilibrium between rces and capillarity of support.

nsity of the surface of a free bubble may be made evident e elasticity and non-cohesion with a like dense surface in y be brought in contact, and in which the surface mole- ons would have to be changed for it to enter. This I may be shown by a pretty experiment with a small ap solution blown at the end of a small pipe, from which erked off, upon the surface of the solution in a vessel his case the bubble will often, after contact, *rebound* for s as a free elastic body. This bubble, when it enters urface, will occasionally take for an instant of time the a to the surface on which it reposes.

ical conditions of quiescent evaporation.

SITION: *That the extensile force of a liquid surface under poration at low temperatures may form points of eva- t will occupy limited areas of the entire liquid surface, aking the functions of bubbles for the escape of vapour.*

conditions of 26 prop. *b*, a vapour forming at a surface es would expand the surface in a certain ratio, which is active as a molecular compression, which may seek another mode of expansion. This modification, I think, may probably be by a protuberant nipple or a *molecular tumerole* of invisible dimensions.

c. Under the general conditions of evaporation resulting in contiguous compression of the surface of a liquid it appears to me that the principles generally offered for the fluid state will show a nearly sufficient cause, which will be relative to the conditions of the last proposition. This we may conceive in that a fluid is a body the molecules of which will not bear pressure upon one side more than upon the other without moving from the excess of pressure. The force of gravitation will of itself, cause every molecule of a liquid to seek the lowest point, and thereby jamb, as it were, its fellow molecule, so that at the surface, the pressures upon the sides and bottom of every surface molecule will be greater than the pressure upon the top of it, although the extra pressure upon the lower surface of the top molecule may be only equal to the action of gravitation upon the mass of the superimposed molecule itself, leaving the surface molecules in vertical equilibrium (16 prop.). Therefore, as the side pressures will be jambing by their excess all surface molecules under every condition, these will be in the most unstable state of equilibrium of the liquid mass. This constant upper minus pressure and internal jamb will influence a surface molecule to constantly move upwards against the cohesive attractive forces surrounding it as demonstrated for capillarity, 18 prop., particularly as it will in any possible downward movement be strongly resisted by the more solid construction of the liquid immediately beneath it, and that it cannot move to a lower level by its gravitation or cohesion. In this manner also, any small movement of the aerial surface, by which one molecule is made by the most infinitesimal quantity to be more prominent from any cause than another, this molecule will tend to be ejected from the surface by the elasticity of the system and the closing of the lateral compressed circumferential molecules around it, and under it, in their endeavours to restore the equilibrium of surface gravitation. In this case the particular molecule selected may overcome cohesive forces, and even be ejected with a force proportional to the excess of elastic compression over cohesion of the surface molecules, which [illegible] them to close the space beneath it. If we imagine such d molecule in this case as one evaporated; for the further of the evaporation after the surface is broken, it only betion whether the ejected molecule, has or has not, some

nective molecular construction with other free molecules,
ossesses elastic force sufficient to support itself at its
above the liquid surface, so as to become a free mole-
le vapour such as we see seething in mass over a boil-
r to evaporate to a gas after its ejection.

any conditions, if the elastic surface force is sufficient
slightly distended liquid molecule, we may observe that
his molecule is free, the entire surface of the molecule
exposed to evaporation by the perfect release from
tic forces that surrounded it formerly when it was a
iquid system, so that it will not again interfere with the
which it was ejected, unless it is pressed into it.

above theoretical considerations it appears to me that
be only a certain number of points under quiescent
in which the liquid evaporates, although this number
ll times very great, and that these points will, by the
surface extension, be equivalent to *molecular bubbles*, or
ıeroles. At the position of such constantly forming
ımeroles the evaporation may be carried on by a con-
ɔn of molecules separately. The series of molecules
he surface next beneath the extreme surface would in
up the gap formed by the extruded molecule, and by

g. The principle of evaporation by infinitesimal bubbles, by surface expansion upon this hypothesis, may be roughly shown diagrammatically as follows as a trial hypothesis for perfectly quiescent evaporation.

Let Fig. 33 be a surface under quiescent evaporation. Let the expansive surface force place the whole of it in unstable equilibrium of molecular compression. Let forces, extending to a distant surface represented by the arrows, press upon a molecule above that is assumed from any primitive cause to be one most out of equilibrium of the surface series; then would evaporation by distention of surface constantly occur at the same point, this being the weakest, to resist surface expansion by heat forces.

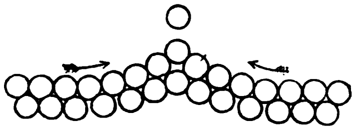

Fig. 33.—Molecular condition of Surface Evaporation.

h. Under the above conditions it will be seen that any force which causes a surface disturbance, and thereby necessarily produces convexity on parts of the liquid surface, that the evaporation will be by this cause rendered much greater.

i. It will also be readily conceived, that having a system of tumeroles established on a surface of sufficient extensile force to produce such tumeroles closely together, that there would be a tendency for one tumerole to break into the other, and thereby ridges or lines of evaporation. Further, if evaporation be by cause more intense at one side of an aerial plane than another, uld lower the side of the plane and perfect equilibrium of ould be destroyed. Under this condition the tumerole or be deflected on one side as in Fig. 34, above, or overflow rely as in Fig. 35, and evaporate at the edge of a mole-

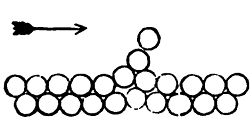

Fig. 34.

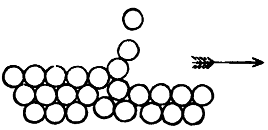

Fig. 35.

y the constant movement of ridges, that would be
d and take one direction.

condition, I have been able to approximately observe
ent. Thus, if we intimately mix fine dust, as, for in-
lycopodium with a drop of alcohol, and observe it
roscope, the surface plane will be observed to be con-
as overflowing currents to the evaporating edge of
re a horizontal circulation keeps up the same system
n on the absolute edge by rotation engendered in
f intensity. The same outward extending form of
also occur in evaporation from capillary tubes, in
ensile surface of the liquid, 18 prop. *g* would be con-
upon the surface of the tube.

r little experimental demonstrations for much of this
ut there is one class of facts which may give some
the molecular tumeroles proposed, under perfectly
poration; this occurs in cases where gases or vapours
resistant surfaces of some semi-fluids, as in the floors
particularly in mud volcanoes, and the same principle
observed in the formation of the cones of volcanoes
relation to the general cohesive surface of the earth.
in these cases from the more resistant surface is by

CHAPTER III.

MOTIVE FORCES ACTIVE IN FLUID SYSTEMS IN THEIR MOVEMENTS TO AND FROM THE STATE OF EQUILIBRIUM OF REST:—FLOWING FORCES.

29. Proposition: *Every free motion of a fluid is a movement towards equilibrium with surrounding pressures. The fluid in this motion follows the most frictionless course.*

a. It is well known as a physical law that a unit mass of gravitating fluid has its molecules in such a state, when they are at rest, that equal gravitation force presses upon every stratum at the same depth in its system, and that this force is everywhere *per area* as the entire weight of the fluid above the same area exactly.

b. If force be impressed by other means than by the simple effect of gravitation, as by heat expansion, or a pressure in a part of the system, the fluid thus impressed extends this pressure in a certain small space of time with equal force to all sides of its containing vessel, *per area,* as far as the fluid extends, so that every particle, if not further disturbed, rests finally in equilibrium, and the force with which the one part of an inscribed mass was impressed, is now equally impressed *per area* on all other parts of the same fluid plus the effects due to gravitation (*a*).

c. In a liquid issuing from a vent, its movement will be at every instant directed to restore the state of equilibrium which has been disturbed by the opening of the vent, and the movements will be greatest where the pressures vary the most. The liquid will therefore be moving from all parts towards the vent, proportionally to the differences of molecular pressures in the parts of the liquid and the resistances offered by other parts. The minus pressures upon h molecule being in this case situated towards the vent by the resistance in this direction, and the greatest pressures, upon gravitation plane, will be upon the most distant parts of om the vent. The nearest possible condition of motive ill be established by a system of pressures decreasing tio from the most distant parts up to the vent where are entirely released.

from a vent embodies many conditions that may be practice of hydraulics, and the components of forces this efflux have engaged the attention of nearly every rodynamics; however, exact laws have not heretofore ed, or even such components as may reconcile theory I will therefore follow this matter in detail for such ns as I may be able to offer.

ITION: *That in the movement of a liquid toward a hole of a vessel, the hydrostatic pressures will act directly ion in the parts of the liquid vertically over the hole, and in the parts of the liquid horizontally contiguous to the a of efflux of the liquid from the hole will be the mean e impulses of vertical and horizontal pressures; except ea of the hole where the directive forces will enter into*

quently, if a hole were now opened in the bottom of the vessel so as to remove resistance from this point, as at A to A′, then the water from C to A and from B to A, supposed a thin stratum inside the vessel, and very near the bottom, would be a part of the water that would be first induced to move towards the hole, this being the part of the system most compressed, therefore more especially influenced by the minus pressure at the hole.

c. If we take the hole to be a point for the sake of omitting the conditions of its diameter; then the parts of the stratum of water upon the bottom surface of the vessel would be equally moved in every horizontal direction towards this point at the same time, and with the same radial velocities; that is, they would move towards the hole by pressures varying inversely, for any stratum, as the squares of the distance into the pressure of the head of water above the stratum taken. Under these conditions the movement from C to A would be equal to the movement from B to A, but as these moving forces are opposite in direction, we may imagine that, in so far as the horizontal impulses of the parts of the lower water moving towards the hole would have power to act by their direct momentum, that the water would be jambed by their opposite directions, and thus form a resistance to efflux, by a kind of compressed constructive arched circle of the water round the hole, and the action of these horizontal forces would thereby *contract by their pressures the free area of efflux* in proportion to the forces of impression upon the descending column.

d. That this is the actual condition present may be partly demonstrated experimentally by inducing in the general system of motion of water in a cylindrical vessel a greater than average resistance to the horizontal impulses of the lateral parts of the water, so as to withhold a part of their lateral impulses from the vertical descending column at a position directly over the hole. In this case by my theory the vertical column would be projected through the hole, and the horizontal forces would remain in their arched static position in the liquid above the hole. This effect may be produced experimentally in water flowing from a hole in the bottom of a vessel by giving the water a slight motion of horizontal rota-ti. The tangential forces of the revolution will then slightly se the horizontal pressures which act as resistances, and them from direct impulses upon the vertical column, so tical column will now empty itself out through the hole, and a clear aerial pipe will be formed from the surface of the water to the hole.

e. By the conditions offered in the last proposition *a*, we assume that the hydrostatic forces above the area of the hole are exactly equal to the vertical forces over all other horizontal parts of the bottom of the vessel *per area.* Therefore other parts of the fluid of equal depth will be equal in motive energy to the parts near the hole, or, for instance, to those surrounding it, so that if we were to take a narrow ring of the lower stratum of water surrounding the hole, and conceive that hydrostatic pressures were equal in all directions, the pressures of the lateral horizontal forces upon the column directly over the hole in the vessel, would be exactly equal to the vertical forces of the water in the hole at the exit of the vertical column; and the vertical and horizontal forces would be equal. The vertical forces in this case may be assumed to be arranged proportionally to their freedom from resistance radially *from* the axis of the descending column, and the horizontal pressures arranged as resistances also radially from the circumference of the vessel *towards* this axis. Then it will be clearly seen that the vertical descending forces will act directly with gravitation, and the horizontal pressures directly as resistances. The outflow of water would be necessarily as the mean of these forces. It will be seen by this construction, taking into consideration the perfect resistance of the bottom of the vessel to all hydrostatic forces except those over the hole, that the flowing forces do not form, *a resultant of the composition of horizontal and vertical forces*, but that the entire vertical forces are *direct*, and that the entire horizontal forces which are deflections from the lateral vertical forces act as *resistances*, so that, supposing these are equal about the hole, the outflow would be equal to that of exactly half the area of the hole, except for the gravitation forces in the water directly over this area, where the direct horizontal forces would lose their quality of resistance and enter into composition with the vertical forces.

f. To satisfy the conditions of the horizontal impulses being direct and resistant in the above construction, we must, as before stated, consider the hole as infinitely small, as the resistances of the bottom surface of the vessel, which deflect the gravitation forces from direct to horizontal impulse, will cease to act quite in this manner after passing the edges of the hole. Further, in the direction of movement of the horizontal forces towards the hole here supposed, every lower surface plane would possess a certain amount of *carrying force* towards the hole, so that a particle of liquid descending on the lateral parts of the vessel would not quite reach the horizontal plane of greatest pressure before it was deflected towards the hole. Therefore it would not offer resistance at the hole equal to a horizontal force *exactly*, but rather according to its moment in an oblique direction at its last position, towards and over the edge of the hole. Further, within the space of the hole such oblique directions as are induced within the efflux, would be active beyond the inner edge of the hole, and would therefore carry their impulses directly towards the centre of the issuing column, and this would cause the assumed jamb of the horizontal forces to be outside the surface of the vessel instead of directly over the hole within it, that is, if the hole were made in a material assumed to be very thin. The vertical forces by this cause, would have the equivalent value of a greater fall in the greater height to the same exterior point, which would be the point of actual resistance to the vertical column. Therefore the efflux volume of the liquid would appear to be greater vertically than that due to depth, proportionally to the size of the hole by an exterior quantity, and we may assume, that directive pressures would react by further deflection of the current to increase the aperture of outflow, above half its area as just assumed (*e* above) for components of vertical and horizontal forces only.

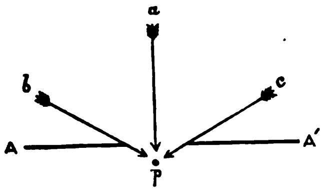

Fig. 37.—Diagram of Direction of Forces.

g. This principle may be shown by the above diagram, where the bottom of the vessel is represented by A A′. The vertical force by the direction of the arrow *a*, and the deflected horizontal pressures by the direction of the arrows *b* and *c* which meet at the point *p*, the theoretical focus of the resultant of the component forces acting at the hole. In this manner, the ascendency of the directive force in the vertical column over the horizontal would render the force of pro-
hyperbolic, so that the focus of the composition of deflected

hole would be somewhat lower than that derived from ective forces in the vessel. The above conditions relate nditions of aperture for efflux of the water by comirective forces only, and do not in any way touch the of energy of the system, which will be taken pre-

ngraving Fig. 36 the bottom of the vessel is made for wide as the vessel is high. This is immaterial, as the gives the ratio to the equal horizontal directive forces ontal plane about the aperture, which will be found for all areas of sufficient extent to give directive imiquid at its efflux.

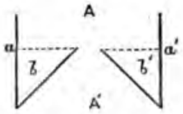

Fig. 38.—Diagram.

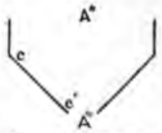

Fig. 39.—Diagram.

le were interiorly conic, as in Fig. 38 above; the resistnclosed volumes *b* and *b'* would be equal to the hydroes upon them at the bottom of the vessel previously e area of outflow would be nearly the same as with a tion of an exterior short pipe leading from the hole at the bottom; the vertical force becomes the greater component from the excess of hydrostatic pressure due to the excess of height, and therefore the horizontal is no longer equal, and the efflux area becomes greater proportionally as the directive resistance of the horizontal force is less. The same principles will apply to horizontal efflux area by a short pipe; neglecting friction in all cases.

31. PROPOSITION: *That a column of liquid falling by free gravitation, will possess motive energy exactly the same as any other coherent body, or as a solid, which will be for its velocity and mass conjointly as the height of its centre of inertia into the height that it falls.*

a. If we apply the above proposition to the fall of a liquid through a hole in the bottom of a vessel, and make no consideration of the cohesion of the liquid to itself and to the contiguous parts of the vessel surrounding the hole, this will be the *measure of the force of efflux.* We may further assume that in a small liquid system, not complicated by intricate parts, by pipes or otherwise, there will be little force lost by friction from cohesion in direct mass movements, so that the direct fall of a vertical column in an open liquid will measure very nearly correctly the potential energy that the liquid possessed in its static position, by the gravitation velocity engendered by its weight, falling the average distance of every separate molecule in the column; this may be taken as the unit of force of a gravitation system which may be used as a measure of the *entire motive force,* and this *force value* may be divided or subdivided into other quantities, but cannot be exceeded by any means; or be lost except by the friction of the system of forces considered; which are here supposed for a simple system, as for instance, that from a hole in a thin plate, to be very small. Upon these conditions the outflow from a hole in the bottom of a vessel will be as the *full area of the hole, to the gravitation force of the liquid above it simply.* By certain causes the efflux may be a quantity less than this as by friction, and by any excess of velocity caused by the energy of elastic forces, increasing the velocity of outflow to be hereafter considered; but we shall find that this increase of velocity will be pro-ortional to the diminution of efflux area; the excess of velocity g as the conserved elastic forces in the compressed fluid about le. In this and in other cases, the entire motive forces will not energy the entire volume forces due to gravitation of a

ding vertically over the hole of the full diameter of the
ng upward to the surface of the water.
e demonstration of the above, if we describe a circle
tom of a vessel containing water, and measure the static
water directly impressing this area, they will be found
y proportional to the weight of the water standing ver-
the hole. Now, as the weight is derived from the
vitation upon the water, and that this fluid is throughout
ucture, we may consider its *static force* as the gravity
e system, which may be expressed by gh for any unit
l we may take this to be the exact measure of the
orce active as a constant outward pressure upon the cir-
have taken, which can never be *exceeded or diminished,*
ant forces upon the same space upon the bottom surface
y the hydrostatic force or weight of the liquid above
ow as the water is assumed in this proposition to be a
ly of equal structure throughout, as represented by a
ding over the hole, and that it moves in falling from
he *whole space represented by the height,* and from the
m *for no height distance* whatever, the outflow from the
entire aperture will be equal to the fall of the water of
meter as the hole for *half the height of the column of*

manent, so that, after impression of any force that diminishes its volume, it will react immediately, and will return to its original volume when the pressure is entirely removed. In this process the pressure may be impressed in any direction, and removed in any other direction, with equal effect of reaction. So that if we were to take the condition of the pressure upon a stratum of water upon the bottom of a vessel with vertical sides, this pressure would be in every direction proportionally as the entire weight of the water above impressed the elastic forces of the *lowest stratum of it.* The energy of compression would be as the *conserved momentum of the descending forces of the entire liquid by which the compression on the bottom* of *the vessel was formed.*

b. Now as pressures in liquids by our proposition, will be ready immediately to react, the action of gravitation on a permanently elastic mobile fluid will not engender a velocity by the removal of resistance from any part of the lowest stratum, for instance, from a hole in the bottom of a vessel as of a body falling the mean height as it would be in an inelastic system, but as the compressions upon the lowest stratum which would represent in motive energy twice this amount as the motive force in this case cannot be assumed in equations as the mean, but as the lowest stratum which is double the depth of the mean. Therefore if gravitation forces for any vertical column of equally dense fluid be represented for velocity by a body falling from the mean height by gh; then by reaction of elastic pressures upon the lowest stratum, the velocity at issue from this would be as $2gh$, giving pressure and velocity one sign.

c. As I have already shown in the last proposition, that the entire energy of a liquid flowing through a hole in the bottom of a vessel, will for the entire area of this hole, equal the velocity of a body falling half the height of the column above (gh); it will easily be seen that elastic compression, if it occurs, is wholly due to resistance to gravitation; for if we were to consider the weight of a column of water resting on the bottom of a vessel as gh, and the resistance as being equally active in opposition to gh, the compression of an elastic system would be $=2gh$; or if we take the hydrostatic force gh, and resistance of the bottom of the vessel as equal to gh, and we remove resistance, that is, one gh, the direct impulse of gravitation be through the elastic system for the instant $= 2gh$. Further, astic force would rest upon the whole area of the bottom l. at the instant of opening a hole in it, this force

32 Prop.

so that the efflux from such a hole would be for the
the hole, and for the first unit of time that the elastic
react, equal to $2gh$ in velocity, that is, equal to the
the lowest place in the liquid in the vessel; this force
from the conservation of energy of the liquid falling
ompression on the bottom, as shown at the end of § *a*
is would continue to act in diminishing intensity during
the elastic forces. But as soon as the elasticity caused
nces *had reacted*, and that a kind of motive equilibrium
by equality of pressures surrounding the hole (30 prop.
rea of the motive aperture would be partially closed by
projections, and a value equal to gh restored for the
rea into pressure.

bove conditions of the action of resistances in forming
ession in a liquid, it becomes clear that the elastic
resistance act *plus* to direct forces. Therefore, we may
stance to gravitation to engender an elastic compression
ompression being equal to twice the direct impulse of
hich I take for velocity or pressure as gh. So that if we
engendered either through resistance or by direct force,
ally represented by $2gh$, and it will follow that as the
compression in a liquid is caused either by a plus direct

of area, so that the fluid will have its *volume restricted in exactly the same proportion as it will have its velocity increased.* Under these conditions we may take the compressed elasticities due to resistance as equal for velocity to $2gh$ for both vertical and horizontal forces; the volume for unit of area of efflux will then stand in equation with the hole as $2gh$ for *vertical*, and $2gh$ horizontal, every particle directed towards the hole acting as resistances, therefore the volume will be for area (a) and pressure in equation $\frac{1}{2}a.(2gh)$, the volume of possible outflow being equal to that of $2gh$ for half the area of the hole, which must, in this case, be considered as infinitely small.

f. For the investigation of the functions of the diameter of the hole we may conceive that at its margin the impulses of horizontal forces will cease to act as resistances to the efflux, but they will leave the impression of their directive moments in elastic compressions upon the vertical column descending by direct gravitation, into which the horizontal forces will now enter in composition. So that the elastic forces engendered by the resistance (b, c) will diminish towards the central area of the hole, and be deflected and leave the vertical forces alone active. So that if we were to enlarge the hole indefinitely the liquid would fall in the central area as a free gravitating body; and as I assume little resistance from the now distant margins of the hole, there would be no elastic reaction in the central part of the efflux; therefore the area of central efflux would be the full area falling as the velocity of the mean height gh as before. Upon this principle, as all holes have dimensions, the velocities of efflux will be compounded of the forces represented by $2gh$ and gh, and the areas of efflux between *half* and the *entire area.* The values of which for holes of moderate dimensions I will now proceed to discuss.

g. I have shown, 30 prop. *b*, that the compression will be greatest upon the bottom stratum of water resting in a vessel, and that in the case of a hole in the bottom, that this stratum would be the first to move by the reaction of the elastic forces, but the motive activity of this compression must be proportional to the nearness to the hole; for although compressions will aid in impressing elastic force for velocity, the water on the distant parts of the lowest stratum cannot reach the hole to displace other parts that are crowding towards it
equal or greater force, therefore the entire compression on the
ssed lower stratum of water will not project its force quite
y, as the water will receive part of its impulse from the

mentum of all parts of the water moving towards the re at the hole, as discussed 30 prop. *f*. We may, therefore, t the *most compressed*, therefore most active, lower stratum will have, as before proposed, a certain energy of *carry*-ards the hole upon the strata above. Thus in the general of forces of efflux, this directive impulse will act at a *of inclination* to direct gravitation in pressing towards hat it will form a *resistance* to the descent of the vertical ss energy than if it acted at an angle of 90° as previ-ed for the directive influence of the bottom of the vessel; pulse at this angle will increase the volume of efflux to reater than half, as it would be, if the horizontal forces sed quite horizontally as before taken, 30 prop. *b*.

we take the resistance due to the moments of the efflux ter through a hole in a thin plate, as proposed in the ph, to be as the co-sine of the angle of inclination of hydrodynamic resistance to vertical efflux, then the s will act directly as this co-sine in the moving water. case the *elastic compressions will vary as the depth of ions of all the particles that can move towards the hole.* If er we can by any means, as by the form of the vessel in ole is made, conceive resistance to efflux within the that the elasticity of the system may increase the velocity of efflux above C H′ in any proportion to a body falling freely by gravitation from any part of the distance C H, the height C H′ being equal to *h* as before, and the height H H′ being equal to $2h$ proposed for pressure only. The hydrodynamic force $2gh$ being equally impressed at B and B′. If we consider the carrying force (§ *g*) to give direction to the particles of falling liquid upon a plane represented in section by the line H′ I, circumscribing the hole at like angle to the horizon;

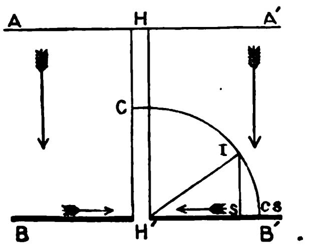

Fig. 40.—Diagram of Directive Angles.

we may then take the lineal values in the inscribed segment H′ I B′ to represent proportional areas to the lines. The above being accepted, then the resistance to gravitation impulse of such particles as fall upon plane H′ I to the efflux through the hole will vary as the co-sine of the angle I H′S as represented by the space H′ S to the radius H′B′; this last being taken to represent perfectly horizontal direction of resistance. I have before shown that the resistance may theoretically in extreme cases equal the direct forces, so as to increase compression to double the mean gravitation forces, and decrease the efflux area to half. Now, if the radius H′B′ which represents horizontal resistance be taken as a quantity $=gh$ as plus elastic force, to a direct gravitation system; the co-sine to the radius of the angle I H′ S, may be represented by $gh.cos$ I H′ S; the equation for elastic reaction being then $gh+gh.cos$ I H′ S expressed in lineal values. Further the deflection by the plane H′ I which increases the area of efflux above half, may be represented by a circumscribing area proportional to the lineal versine, or as the space S, C S to H′ B′ and the equation for area may be represented by $\frac{1}{2}a+\frac{1}{2}a.ver$ I H′S, ½*a* being that previously proposed for horizontal impulse exactly, ½*a*+½*a.vers* I H′S being found experimentally to equal ·61 of area x, allowing ·01 for friction of the system.

angle between the carrying forces and resistances taking t at unity, may be found by the formula $cos\,\theta = \frac{1-(P^2+Q^2)}{2PQ}$,

ng the angle, and P and Q the carrying force and resist-
ively. This I find by calculation to be 42° 29′ 35″ for a
n a thin plate omitting corrections for diameter of hole.
gle given above must be considered as the equation of a
d for values of inclination in parts; but as the velocity of
n an incline is the same as through a cycloidal arc, which
curvature, the areas of efflux would be as the incline into
nearly. The form of curvature would be actually *para-*
er nearly static, or in rotation, as 43 *art. ante* will show,
n the corners BB′, and the velocity of impulse of carry-
uld increase in inverse ratio as the squares of the distance
nt where the elastic forces would be released. The
s of these forces would by the means proposed give a
path for the lateral particles and for the directions of
the hole; but as gravitation acts as a constant quantity
the process and the movements of this force are directly
rabolic trajectory would be really induced which would
versely and approximately the path of a projectile
ly vertical from the earth.

bove conditions it is seen that the lateral impulses resist
npulses and regulate the area of efflux. It will also be
nis area will be *constant*, for if we increase the vertical

the elastic forces before absolute issue, that we might increase the area of efflux in any proportion until the liquid issued at the full area of the aperture at the velocity gh as proposed. This must evidently be done by increasing the area of aperture constantly in direct ratio, that the compressed elasticities in the water are able to react by the mobility of its system. It will also be very clear that the form of aperture to produce this effect will be that of a frustum of a cone. With such a cone as here proposed it is said that Eytelwein by refinements of experiments of Venturi, but not acting on principles here given, was able to obtain efflux equal to a free area of ·98 of the aperture, ·02 only, being lost by friction, for what I consider the perfect equation of area for velocity equal to gh. This condition of the velocity of issue from such cones I find easily demonstrated by experiment. Thus, if we construct a vessel so that by an aperture we may project a jet upwards through a hole in a thin plate from a supply cistern above, as shown and described on page 108, and measure the height of the jet so projected, we find that it reaches nearly the height of the cistern. If we now take half the height of projection, and construct a frustum of a cone whose area nearest the vertex equals the area of the hole, and at its base twice this area, and place this vertically over the hole, the liquid will then have insufficient projectile force to rise higher than the inverted cone, and will simply overflow smoothly at its mouth. For the friction of water through a cone which causes the small loss of ·02 only of area, I will show the conditions further on.

o. If we consider the efflux area from a vessel to be derived from gravitation and elastic forces conjointly, and if these are proportional for one height, they will be proportional for all heights in like ratio for issues from the same form of aperture and under the same internal conditions, in all cases. Thus, supposing we have a thin vessel pierced with equal holes at equal descending depths, and we measure the efflux area of the first hole in ratio to its gravitation and elastic forces for its volume and velocity, all holes lower will be proportional to the depth of the first. Thus, assume the influences to be due equally to gravitation (g) and elasticity (e), so that half the effect is due to each for velocity and volume of issue;

then for efflux, $\frac{1}{2}g + \frac{1}{2}e =$ height of *first hole*,
$g + e = 2\,h$ second hole,
$1\frac{1}{2}g + 1\frac{1}{2}e = 3\,h$ third hole,
$2g + 2e = 4\,h$ fourth hole,

and so on, or we may say of the fourth hole in relation to the first that the liquid issues with double the volume and double the elastic compression $=4h$. If we add a pipe or cone, we may increase gravity area of efflux in any proportion until finally the elasticity disappears, and the fluid issues in volume equal to the aperture, with velocity equal to a body falling not less than half the height of the supply cistern minus the friction of the aperture, as in the cases of cones just discussed.

p. As in the projection of a liquid from a thin plate, the horizontal forces may be assumed to project their impulses beyond the edges of the plate into the hole, and as Eytelwein was able to construct a cone that delivered so much as ·98 of the aperture, and that from a hole such forces being free in a thin plate to enter into composition with the vertical forces; it became difficult, upon my conception of the principles of efflux, to see how the edge of the hole in a thin plate could offer any measurable resistance to the outflow; as the thin plate must offer much less surface friction than a long cone, therefore, a jet projected upwards from such a thin hole should rise very nearly the height indicated by the forces present at its efflux, in so far as the friction was concerned. If the elastic forces at the hole were equal to $2gh$, the efflux by reaction of elasticity (32 prop. *a*) should project the water the entire height of the supply reservoir. I therefore devised the following experiment to try this.

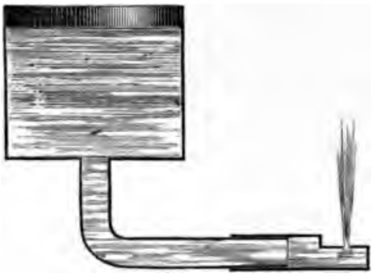

Fig. 41.—Ex. Upward projection of jet.

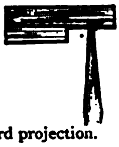

Fig. 42.—Ex. Downward projection.

q. An iron cask was connected with a pipe of 2½ inches in diameter as shown in the engraving above. Upon the end of the pipe another piece of pipe was fitted, so that it could be turned at any

32 *Prop.*

angle to the first. After closing the end and cutting exactly half this pipe away lineally near the end, and filling in the cut part with a flat plate (the drawing is incorrect, it shows less); the end piece described could be turned in any direction about its circumference; so that a line drawn along the centre of the upper part of the surface-plate would keep one position in space. Now making a hole central to this line on the plate, and fixing another very thin plate with a smaller hole over this, I could direct a jet upwards or downwards from the same spot. Means being taken by the principle of overflow of keeping the water in the vessel at one height.

r. By fixing two rules vertically, in such a manner that one was at a distance of 6 inches before the hole, and one at the same distance behind it, the eye could, by looking over the edge of the two rules, at once measure the height of an intervening jet by the incidence of the lines which could be seen simultaneously with the jet. With this apparatus, the water in the reservoir standing constantly at 38 inches, a jet was projected, when this projection became moderately steady, 37 inches. The projection (not the force) being $\frac{1}{38}$ less than the entire height. This loss would be due to resistance of air, friction of apparatus in deflection of directive impulses and side contact, and minus velocity from the composition of forces in the vessel and in the diameter of the hole. At this height it was quite clear that all the water from the jet did not reach the apex. It was also clear that it had to support a greater volume of water than that which would equal a constant jet of the size of the issuing column, for the column of water issuing from the ·25 of an inch hole was spread out at the vertex of projection upwards to a cone, whose base was as nearly as I could measure ·65 of an inch in diameter, so that perhaps the extension of the column equalled by resistance, the imperfect projection for height. By comparative measurements I found this cone of similar form to that which in a conical pipe would permit the greatest volume efflux from the vessel.

s. The jet was now inclined at an angle of about 5 degrees to get the greatest elevation, and the water flowed over the edge of the projected cone just described, the path of projection not being in this case parabolic. To ascertain the resistance from interference of direct projection by the returning water, I reversed the movable e apparatus by turning the jet downwards, as shown in the stration, and calculated the relative outflow from the two me for a given volume of water.

above experiment I placed a glass tube in the supply shown in either illustration, with a bulb blown at one e being kept upright by a covering tube, in which it slide; a hole was ground in the face of the outer tube, aving index marks. With this apparatus the water was low out of the cask until the glass tube sank to a line ch corresponded with a line upon the hole in the outer , in which it was placed, having a similar line on the ube for a starting point. With this the time of overflow from one line to the other was taken, which time occu- ard projection 10 minutes 45 seconds. Now, reversing hown in the second illustration above, I found that the ty of water from line to line flowed out downwards in 1 seconds.

eing 4 seconds difference of time due to additional resis- pward over downward projection, showed the projection as the force of efflux for the highest part of the jet, erence for upward and downward projection being only the whole time. Further, in the downward jet there nal forces derived from cohesion of the water, conditions have yet to consider, but which I conceive accelerated rd projection by a quantity as great as may possibly zon for area of volume = 42° 29′ 35″ (*h*); *d* B′ X final angle of projection of forces within the vessel; giving the velocity of projection from the compressed elasticities of the last motive part within the vessel shown upon the vertical Y. This forms the motive angle of projection

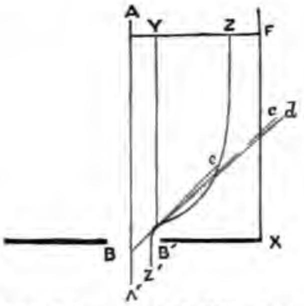

Fig. 43.—Diagram Path of a Falling Particle.

into the boundary of a column of the diameter of the hole. This I find subtends an angle to the horizon of 41° 7′ 34″ or $= \frac{\sin.\ c\ B'X}{\sin.\ d\ B'X} = \frac{H}{H'}$, $\frac{H}{H'}$ being equal to $\frac{37}{38}$. As there are many difficulties in the experiments, I only assume the above approximate, and most probably *c* B′ X and *d* B′ X should be one angle; *e* B X angle of composition of forces for the area of the hole within the projected column, which gives to the issue a slight minus velocity, from inclination to the horizon = 65° 33′ 47″. The angle is drawn in the figure above at about 45°; my first conception of it by equation of the composition of moving and static forces. It should be in equation with the moving forces only between 41° 7′ 34″ and 90° (vertical).

w. A particle falling from Z will be deflected into the column issuing at A′ in radial position to the semidiameter of the hole A′ B′ at Z′, as Z was to A F at its starting point near the surface in respect to the hydrodynamic forces upon it, that is, neglecting all function of the friction of its motion; the general conditions of which will be taken in the next chapter in more demonstrable phenomena.

33. PROPOSITION: *A unit mass of fluid is a self-contained cohe- system of matter. It will conserve its motive elastic forces if ; or these forces may remain in the equilibrium of rest within its lthough in contact with other motive systems of fluid matter rent; except in so far as the exterior systems, by friction* *usion within the fluid mass, may impress their motions in it.*

ell known that any number of communicating vessels gas will communicate the pressure the gas receives in t, after a time, equally over the whole surface of the

resting in a quiescent state, as water in a vessel, or in of communicating vessels under equal pressure, will tation equilibrium after any disturbance which produces e part.

uid systems of distinctly different densities are in conll not necessarily, in the same way as the above, comeir motive forces or pressures to each other as they unicate these forces to the same system of matter; but ication in this case will be conditional to the material tems of the fluids and their powers to embody the tions or pressures through motive intermolecular elasthe one fluid to the other.

t proposition very generally offered in hydrodynamics ibrium of fluids is that when a mass of fluid, supposed t weight, is subjected to a pressure, that the pressure is throughout the whole that all its parts are equally fact as it practically exists. The proposition infers that, the equilibrium of a fluid may be partially confined to its own elastic system, which will be within the limits of its forces of cohesion, and that motive forces or pressures will not necessarily be entirely communicated to other material systems beyond its own system in certain cases; this the following experiment will demonstrate.

d. Let A A′ be a bent glass pipe of ¾ of an inch in diameter, each bend being 6 inches, containing air from B to C, and water at all points below this.

Let S be the surface of water in a reservoir in communication with the glass pipe, at 8 inches above the surface A′ in the pipe. Now if pressures and forces were equally communicated or diffused through contiguous systems of fluid matter, S and A′ should rest in equilibrium at *one height,* minus the difference of height C, A′. This should be so in that any pressure impressed at S, as that of gravity, acting on the mass of water in the reservoir, would be equally active on B. And if the fluids could communicate their motive systems of pressures through these forces as hydrostatic pressures, the pressure on B should be equally impressed at C, and the pressure received from the air at C should be equally impressed at D, through the aqueous system, so that all intermediate parts being of equal hydrostatic pressures, the extremes should be equal, and S and A′ should rise to one height, less only the difference of height between D and A′. But as there are in this case by separation, three distinct systems of fluid, the communication of motion necessary to convey pressure from one to the other, will depend principally upon the [illegible]ity *of possible motions* in these systems, which in this case, by differ[illegible]f density, is not great, so that in fact the water in the reservoir [illegible]sts at 8 *inches* above the water at the point A′ in the above [illegible]hich was drawn to scale. The quantity 8 inches is taken [illegible] will depend on the quantity of air in the tube, and

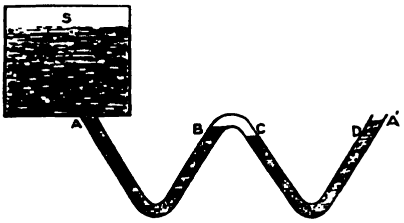

Fig. 44.

nd, 24 inches in the same experiment. This principle
rstood in the practice of plumbing, where a few inches
exure in a pipe will, under certain conditions, withhold
tic force of a head of water of 20 feet or more.

densities are approximately equal, and the fluids upon
e attractive forces between each other, or chemical
impressed forces will act by continuity with a certain
ch will be conditional to these forces. But there will
certain function of continuity of impressed forces by
their own systems, in which the motion is originally
for instance, steam rising in dry air will maintain set
it is invisible, and may possibly do so afterwards; but
oncerns diffusion, which I will hereafter consider.

ory generally offered for the equilibrium of surrounding
mands that the fluid should be without weight, that is,
ity acting more upon the lower than the higher parts;
mobility of a fluid system in its power to distribute
ssibly the heavier or more dense the fluid the more
distribution, as we can imagine in a liquid, for in-
will be less deflection by contained elasticities within
than in a gas. This I infer, in that the elasticities of
will be almost entirely contained within its molecular

least density, hydrogen, would be the least active in distribution of forces. This is, I think, inferred by the resistance hydrogen offers to sound motions.

Traction of Fluids.

34. PROPOSITION: *Fluids having parts moved asunder by a force of not great velocity, will draw after them contiguous parts in ratio; that these are not withheld by greater forces than the mass cohesion of the fluid system. The moving parts in like manner will draw forward other parts, until a motive part engenders by the continuity of its motion a motive system of which the original motion only forms a part.*

a. The cohesion being equal throughout the whole system of a single fluid;—if this fluid is pulled asunder by a force it will part in the nearest plane to the motive force, as any greater distance from this nearest part would have to overcome greater inertia (21 prop. *d*). If any part of a liquid contiguous to a motive part is more free to move, than the cohesion or adhesion to solids in the more distant parts can withhold it, the near quiescent parts will necessarily follow the motive parts. This principle is visible in many phenomena, for instance, it is shown in the manner in which a small stream will run down a vertical solid surface in a close column, or upon the under side of an inclined plane. It is also shown in the manner that a wet cloth will empty a pail of water when it is hung over the edge. In this case the capillary force causes the first rise, which the traction of the water continues, the overflow being independent of th functions of the capillary force, which is equally active to uphold both the ascending and descending parts of the liquid in the cloth.

b. By placing a lathe of wood at an angle of about 25° to the horizon and permitting a stream of water to flow upon the upper end of the wood, this stream will flow along the under side to a depth of about ·13 of an inch without dropping. About twenty years ago I extemporized, and afterwards used for many years, a solid wooden rod of about an inch square to carry my photographic and chemical washings, for about 24 feet obliquely downwards across a yard to a sink, and this simple contrivance conveyed the outflow of
inch pipe as securely as a continuous pipe would have done,
rely avoided the inconvenience from the corrosion of the
that I had previously used.

system of cohesion which causes traction of following

active in a certain degree upon all lateral parts, so that
sive to the liquid, which may be conceived to unite the
em of a certain mass of the liquid, when moving straight
engender a tractional system of motion in the lateral
s, the same as upon all following parts of the liquid.

lues of tractional forces for the above case are well
observation made by Mr. J. Scott Russell; for this I
r. Russell's own words as I find them given to describe
anslation, the properties of which I will hereafter more
consider. I use the illustration now to show the con-
ects of tractional forces which may drag powerfully for-
mass of contiguous water horizontally, in partially over-
resistance of quiescent surrounding cohesions. Mr.
es:[1] "I was observing the motion of a boat which was
n along a narrow canal by a pair of horses, when the boat
stopped. Not so the mass of water in the channel which
tion; it accumulated round the prow of the vessel in a
ent agitation, then suddenly leaving it behind, rolled
great velocity, assuming the form of a large solitary
rounded, smooth, well-defined mass of water, which
s course along the channel apparently without change
iminution of speed. I followed it on horseback, and

seen that the tractional forces equal a certain function of near adhesion.

35. Proposition: *In the traction of liquids, or otherwise cohesive bodies, the parts set in motion that are laterally free, will move towards the central axis of the mass to seek the greatest area of contact. If the moving lineal series of parts be of any figure other than cylindrical, the most exterior parts will be drawn most towards the axis, so as to form a cylinder, or to approach this form.*

a. In 11 proposition, page 30, we have the conditions under which *static cohesive forces* will produce globular masses, by the cohesion of every molecule seeking the greatest area of contact. The same principles will apply to this proposition, but the forces will be *motive* and continuous; therefore the area of greatest cohesion of the molecular parts being in direct lines, will arrange the cohesive matter cylindrically, with the central axis in the direction of motion.

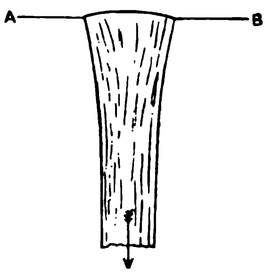

Fig. 45.—Traction of fluids.

b. We may observe the principles of the above proposition in pouring water from a mug. The broad stream which issues over the edge is drawn into a narrow cylindrical stream, and the water stands up in beaded outline upon the edge of the mug, where it is drawn over. In this we may notice that the cohesive force of the water, seeking the greatest area of molecular contact, acts in the same manner as the cohesive forces in homogeneous plastic solids or semi-solids; for, if we use force upon a homogeneous soft solid to stretch its length, as the force of gravitation stretches the stream of water, an exactly similar contraction is caused by this stretching as occurs in the more mobile fluid, and the above illustration, Fig. 45, will represent either the stretched band of water, or of semi-fluid as red-hot glass, or of a metal as cold copper. In which cases the line A to B may represent either the edge of the mug over which the water is drawn, or a mass of solid hot glass, from which a band of glass is drawn, or a vice in which a band of cold metal is held to be drawn by a superior force to that of gravitation.

his stretching, in the above cases of the fluid or other plastic were continued, and the material were sufficiently cohesive, ould constantly decrease in transverse breadth, and a d at length be produced. This thread would break he instant the limit of the cohesive force in the fluidity n of matter was exceeded.

position of stretched fluids to form threads or cylinders tributed to surface tension. I have shown previously forces tensile or extensile would in free matter produce lobular form, where the molecular forces sought the a of contact (11 prop. *g.*), the motive cylinder by this being as the sphere of a static system. This proposi- lirected to the conditions of masses does not take any of surface forces, for the same forms induced by trac- are evident in falling masses of water of many thousand nute, where the surface forces, at most, as components to nust be very insignificant.

found that the molecular tractional force of water may l shown by the following experiment:—Take a glass ut an inch in internal diameter and of about a foot in ace this vertically in connection with a reservoir, so that w through it with small force. Now, if the supply to the e by an aperture or pipe of a quarter of an inch circular is certain that a larger stream than this of ¼ inch cannot ne glass pipe. Therefore, if the pipe be allowed to fill opped at the end and then released the water as it over the end of the pipe, in which there is a triangular opening as shown in the engraving above (Fig. 47), the stream at issue will be in this case triangular; but it will form a perfect cylinder in about 6 to 8 inches, if the supply force be small. If the stream issue with great velocity from the height of the reservoir, there would be present compressed elastic forces which would cause the stream to distend at issue; the conditions of which I do not now propose to follow.

f. The conditions of contraction of a lineal liquid system under direct strain, would permit the continuity of tractional forces in the centre of the system by lateral supply for an indefinite time, or until the liquid thread so produced assumed invisible fineness, if there were not present surface forces sufficient to overcome the continuity of the system at a certain diameter, as previously discussed. This is possibly the case with glass, which I assume to possess no special surface force, which may therefore, if kept fluid, be drawn to great fineness. But with liquids possessing extensile surface force, which possibly nearly all liquids possess, at a certain point the extensile surface force overcomes the cohesion of the mass, and the thread instantly breaks up into globular beads by principles discussed 23 prop. page 74.

g. Some demonstrations of this proposition, as regards lateral traction, were approximately given by Venturi as principles of lateral communication of motion to fluids. One of the experiments he offers is particularly demonstrative; this is Ex. 1.[1] The horizontal rical pipe A C is introduced into the vessel D E F B, which is

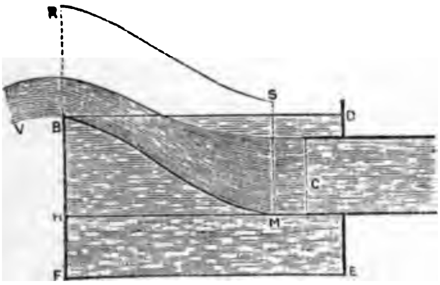

Fig. 48.—Venturi's experiment.

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[1] mmunication of Motion in Fluids, by J. B. Venturi, translated in *Nichol-* ol. ii. p. 173.

ater as high as D B. Opposite, and at a small interval erture C, commences a small rectangular channel of tin R, which is open at top S R; the inclined bottom M B edge of the vessel B. It is 24 lines broad; the diameter A C is 14·5 lines; the extremity A is applied to an in Fig. 48. The water of the reservoir being suffered to the tube A C, the jet rises along the small channel M B, t of the vessel in the stream B V. By this means a roduced in the fluid of the vessel D E F B; this fluid he channel S R, and issues by M B V along with the jet t in a few seconds the water D B falls to M H. The offered fully meets this case, the water in the vessel is *st exterior* part of the system; it will be therefore drawn axis of motion, as in all other cases.

ount and mode of lateral communication of motions in e very important in the consideration of the commumotions to masses of static water contiguous to ocean ich by this proposition are induced to preserve a con-n, or rather to contract the section, and the same prin-e active in moving air also. But these phenomena in complicated generally with other principles of active vill be hereafter taken into consideration.

other density, is assumed at first to move or *drag* with it an infinite small depth of fluid in contact, to which the adjoining stratum is conceived to offer a certain amount of resistance by its inertia, so that it *slips a little from its hold* upon the moving fluid, nevertheless it induces motive velocity upon the *lateral* stratum, by which this second stratum moves with a little less velocity. This stratum of induced motion then moves another contiguous to it in like manner, and this another, until by consecutive strata the inertia of the mass is overcome in diminishing series of velocities by the tractional or *vis a tergo* force; or if the force be continuous at equal velocity, and the lateral mass small, by moving contiguous parts, by which the inertia of resistance is assumed to be overcome, and the entire mass enters the system of the flowing stream as in Venturi's experiment. In this case the value of the cohesive force is estimated in the compound ratio of the flowing surface velocity, of flowing force, of time by continuity, and of *slip*, upon the lateral assumed static fluid. Therefore the lost velocity must constantly be proportionally equal in equal times, in the consecutive strata, to that the quiescent fluid gains, in like proportion, as these velocities on a cohesive system must react equally upon each other. Therefore, if we take the *vis a tergo* force to diminish in the duplicate ratio to the distance, which practically it may do upon these principles in a certain unit of space, the resistance being everywhere equal, the diminished velocity will be as the square of the distance.

k. I have no doubt that the above answers approximately to practical observation in certain cases, as I have proposed 34 prop. for some small distances from the central area of a flowing stream; but I doubt extremely if the principle has any reality whatever, as regards the loss by *slipping* being a function of fluid motion, except that it may represent in a certain rough way an apparent principle of action of cohesive forces. For the motions of fluid *I extremely doubt the possibility of slipping or gliding motions in any form whatever*, for which I shall endeavour hereafter to show reasons. In the present case the *vis a tergo* system, or any other system that may be expressed *by any constant proportional fluxions* that I have met with, will not answer for the lateral communications of motion. This is seen in that *any sensible series of fluxions would require local maxima or minima at a distance from the moving part, to be true to practice, instead of ones in the most distant part or in the extreme distance, as emands.* For instance, I have not met with any form of answers for the motive direction of fluids in distant s of a stream, where proportional motive functions, if be still active, as in this case the *fluxional* force could *atively:*—Whereas experience shows us that a flowing river does not move the quiescent side waters in its own accelerate them, if flowing more slowly in this direction ts of velocity, in any proportion whatever to the lateral versed; in fact, in certain cases which are common we ne entire flowing force of a stream in a wide channel ion in the lateral water *near* the banks *directly opposite ng force.* This, I will show hereafter, is in principle nd *necessarily the case* through the state of elastic cohe- present in the liquid.

ole of the conditions of the above I will hereafter con- nciples as demonstrable as I can make them by experi- proposition here given is confined to tractional forces *erally free* from exterior resistances, and which cause v uniformly to central areas by attractive forces, as de- p. So that this proposition, as regards tractional forces, ne water above the inlet at D in Venturi's experiment in ire, but does not apply to the water under the flowing I.

to the fluid, there will be no resistance, and its form will be preserved throughout its projection, representing at the same time a motive force in the fluid equivalent to an equal mass of it. This form of motion may be observed in clouds that have a specific gravity not greatly in excess of the stratum of air in which they move, and in which they preserve their configurations. So that we may infer that all free motive parts will equally preserve their positions and velocities in flowing matter, if there are not present internal motions active upon external resistances.

b. If we take a case in which internal motions are present that do not disturb the external form in a flowing force, these motions will form a system, whose motive forces will be in relation to other parts of this system *only*, not to the general momentum of flowing force; and if the body be carried forward by the flowing force with the same velocity as the flowing fluid, its mass will have the same entire flowing force as an equal mass of the flowing fluid, although the flowing force of its parts may be different. For instance, the hull of a ship, whose submergence represents an equal bulk of water to the submerged bulk below the water line, would not cause any deduction to be made from the flowing force of the stream in which it may be floated, as the force of the bulk of the vessel moving in the fluid is equal to the same mass of moving fluid, neither would any operations within the ship, as the working of engines or moving of cargo, affect the velocity of the ship or its flowing force in the stream, except these motions cause external friction. Therefore motions that affect flowing forces are exterior or *surface forces* of contact on other matter, which cause by adhesion acceleration, resistance, or deflection.

c. Motions that are exterior to a fluid, and that do not act as resistances or accelerations to its flowing force, may engender motions within the flowing system which will henceforth be carried forward in it, and the motions may cause some parts of the flowing system to move more directly or quickly, and other parts to move inversely or more slowly; as, for instance, a cyclone in the air may be carried forward in a current, and part of the retrograde side of the cyclone may appear on the earth's surface to be motionless air, although it is in *relation* to the motive system of the cyclone, as active as the parts, and the general momentum of the direct flowing force cyclone remains the same in the current as an equal volume ent directed in its stream lines.

OSITION: *All lineal parts of a free flowing fluid not*
xterior resistances, that have a velocity more or less than
velocity of the current, will be constantly resisted, so that a
g too quickly will be retarded by other particles in front,
ng too slowly accelerated by others behind, until the final
he parts becomes equal, and the fluid moves in direct con-
s. The same principles will hold for a cohesive system
otation upon an axis of inertia, where the velocities of the
umferential parts will finally become equally active, or as
f their motions about the axis.

inciples of this proposition are given by Newton in his
They are here discussed to consider certain conditions,
hole forces within a fluid are assumed to be contained
contact. Any parts of the system that have by any
s velocity, will engender compressions upon the forward
arefaction on the backward parts; and after a certain
of time, the compression will be reflected and return
refaction, and equilibrium will be restored in equation
rage velocity of the system. By this means also aerial
and rarefaction, assumed to be engendered by sound,
literated in a short space of time.

roposition does not relate to conditions where the com-have practical application, as components of fluid motion; in which the most free forward and backward parts of a lineal series of parts in a current are ultimately brought to uniformity of motion in their lineal directions, and the flowing force is continued in equation with the forward and backward momentum of the separate parts.

c. For the conditions of a circular equation, if we admit a general principle of cohesion in the fluid, and impress opposite sides of a fluid mass by any means with different velocities, or retard one side of the projection by any resistance whatever, the tendency will be to cause rotation in the mass, so that it will now in its flow describe an arc, or a complete circle, about the superior resistance, in such proportion that the original impulses of the flowing force may be free to act. In a coherent system, an induced circular motion by separate impulses will, if left to itself, after a short time produce and preserve a uniformity of motion in a circular area under the same conditions as proposed for a direct area, without greater additional friction on the entire motive velocity of the moving parts than is caused by the resistance at its tangential and its resting plane.

d. This proposition will be found in practice to apply to central forces of flowing streams. If there be lateral resistance in any part of the stream the motions will not be direct, as I will hereafter show. The proposition is offered as a principle that ensures constancy of velocity over established lineal directions, direct or circular, which causes a continuity of force in lineal or circular areas, where the motive power is derived from a *local cause*, that does not at any time affect the entire area of the fluid projected, but at first or in part only. The proposition is important in the consideration of oceanic and aerial currents to be hereafter discussed.

38. PROPOSITION: *That flowing fluids will preserve the same motive volumes and velocities by cohesion of their parts, and by equation of internal forces, in so far as they are free from internal strains or external resistances to do so.*

a. Taking a flowing fluid as a mass system in motion, it will flow approximately over equal areas in equal times, preserving, as far as possible, a uniform sectional area. Thus, if a stream flow along a and there are bays or inlets in the river, the stream will not be d into these bays, unless there is some exterior point of which makes this the least frictional line of motion; but ll generally induce such a system of motion in the bay al flowing volume may be maintained in the most free e motive conditions under which this occurs will be nsidered. If a stream flow through a lake, there will be lateral motions which render its path of little friction, naintain an equal course, as is seen in a stream flowing ke Constance in Switzerland. The same will occur in a ne ocean.

impediment, as a stone, be placed in the bottom of a water will rise as it approaches this impediment, and of the stone will be clearly indicated by a deflection ce of the water. If the stream pass over a hollow, it it and rise upon the opposite side, so as to continue ately uniform motion as a lineal system of fluid. In the water being raised above gravitation equilibrium, incident waves; but these are complementary phenoe need not follow now.

ive elastic forces in liquids.

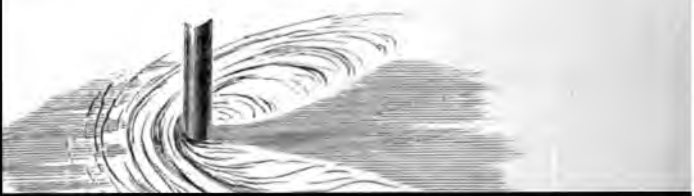
SITION: *If a free flowing liquid is resisted by a solid by its form some less free opening for the continuity of force than that of its approach to the obstacle, the flowing iquid will accumulate its momentum in elastic compression* cule will impinge upon the second in like manner, and so on to the extreme distance, until the projectile force of the mass is taken up in the percussions and reflections, in which it conserves its elastic force equal to the force of resistance to the moving mass. Under these conditions the elastic force of the flowing mass is conserved as an entire compression in *itself*, and in the fluid in front of the resistance conjointly, so that the forces of reflected resistance are compounded with the direct force of the flowing mass. By this means a flowing stream in a free open area will be compressed and partially retained, so that it will rise against the static resistances, but will have its flowing force *increased* in the deflected current thereby, equal to the conserved elasticity of the compression, by which the flowing force acts cumulatively in increasing the velocity ot a smaller sectional area of the flowing force which appears in the deflected stream, exactly as in the cases of the hole in the bottom of a vessel discussed, in 26, 27, and 28 props.

c. If a large surface of impediment is placed in a running stream, as the pier of a bridge, the water will accumulate in front of the pier, and be pressed up above the average liquid surface for a long distance up the stream, and form a conic area of resistance in the water before the running stream encounters the pier; but the average velocity of a stream beyond the bridge will not be much impeded by the resistances of the piers, as the restrained elasticity of the resistance will react and greatly accelerate the water passing through the arches.

40. PROPOSITION: *Horizontally impressed forces in an open flowing liquid, will accumulate elastic compression at a distance in front of a point of perfect resistance, greater than at the same absolute point.*

a. The active molecules of a flowing stream, first coming to a point of solid resistance, will after contact be the *most reflected.* Other molecules impinging upon these, being more distant from the static resistance, will be less reflected from the less static solidity of their impact, and others less, and so on to the greater distance, until the approaching molecule will have a velocity only an infinitely small quantity greater in the same direction, than the re- molecule immediately in front of it, or that the flowing force nass will be nearly equal in direct momentum in the same f motion to the resisting force. *Therefore, although the will be equal in the entire mass approaching the point of* *e reflective force will be greatest at the point of absolute* nd as the reflected percussionary force by its direction approaching flowing force, at a certain point in the e elastic forces in opposition will act cumulatively and irrent with greater velocity than that of the flowing force of least restraint, or conserve the elasticity of the flowcted force, if there be no free egress.

nciples of the above may be shown experimentally, n the central line of a wide open trough an upright peg, a current of water to flow down the trough past this; we serve that the flow of water at its general average height ite reach the peg, or that there is no elevation about ion; but that the reflex action of the resistance of the raises a ridge in the water before the peg is reached, ridge flows outward from the obstruction by a current, ntirely avoids the peg. The surface of the water, as it his case, is sketched roughly below.



water at a constant height at its surface, so that there was a stratum of water a quarter of an inch or more upon the bottom of the trough, enabled me to estimate clearly any resistance to the flow at the bridge by the difference of depth of water near it. The cumulation of elastic force from the flowing current was observable long before it

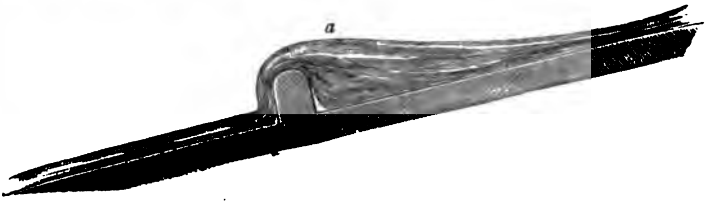


Fig. 50.—Ex. A bridge in a stream.

reached the bridge; but its greatest accumulation was at *a*, as in the figure, which in this case was at about ½ an inch in front of the bridge.

In this experiment, as in that given (12 prop. *c*), cumulative elasticity of the liquid is shown in expansion of volume. The water appears in this case to pile itself near the top of the bridge to nearly double the height of the current in a small stream of a quarter of an inch in depth. The conserved elasticity becomes released after it passes the obstruction, and there remains the same volume of outflow, at nearly the same velocity from the trough as though there were no obstruction.

d. The cumulative conservation of elastic force in front of a resistance becomes an important element in the motive forces of ocean currents, under many circumstances and cases. The general effect being the elevation of the water at a distance in front of the point of resistance, and augmentation of the velocity of the deflected current, where the flowing force and reflected resistance produce the greatest mass compression. Many instances of this principle of force action, that are visible in surface motions occur in ocean cur- nts. One of the most striking of these is perhaps in the western r of the main equatorial current in the Southern Atlantic. This ous current takes its western drift, from reasons that will be r discussed, direct upon the immense eastern promontory of merica, which extends from Cape St. Roque to Pernambuco, axis of greatest average projection at about 7 degrees e. Over this solid point, or rather front, of resistance,

Atlantic equatorial current is said to divide at a dis-
ly 300 *miles before it reaches the front of absolute resis-*
e main equatorial current at 600 miles distance from
, the water is said to flow at a rate of about 20 miles
s, in the deflected current, at 300 miles distance, under
e elasticity of reflective force, it flows at a much greater
s in the northern deflection which forms the Guinea
ate is at about 40 miles a day. The same form of
f velocity occurs also in the southern deflection which
azil current. I will return to this matter when other
e discussed, and the active principles of this form of
carefully investigated. I give this note to illustrate
ce of the principle enunciated in this proposition.

ITION: *If two flowing forces meet at an angle, by which*
istance from each other, the elastic forces of the flowing
e conserved, so that if there is only one possible issue of
, this will carry the fluids when they are thrown together
elocity than they each separately possessed.

ditions of the above are nearly the same as those dis-
op. page 94. It is found that a tributary flowing into
the section is not greater, the current becomes swifter

only in its power to retard direction of motion for the most part, in the area of least possible freedom, the conditions would be as in the following diagram:—

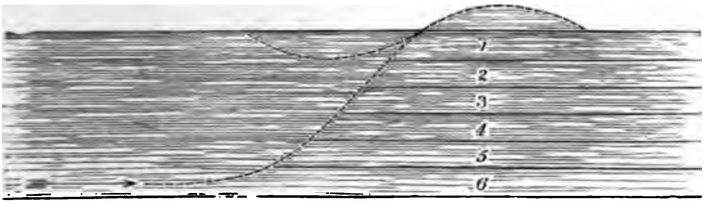


Fig. 51.—Diagram of minus surface resistance.

c. Let the above diagram represent a vertical section of water in a quiescent state. The lower surface being a rigid plane of adhesive resistance. Let the arrow represent a force embodied in fluid matter proceeding in lines parallel to the surface, and to the plane of resistance at any depth. Let the liquid suffer any kind of resistance from adhesion or viscosity greatest at the static lower surface. Now the force, represented by the arrow near the lower plane, finding the greatest resistance at 6, by the laws of fluid motion it will move to the less resistant plane 5. By such movement or deflection it will now possess a directive force upwards from the horizontal plane of its original force, and this directive force, being further deflected by the consecutive planes of decreasing resistance, will consecutively deflect the force more and more, as shown from 6 to 5, 5 to 4, and so on, until it reaches the surface 1, or the plane of least resistance. Now above 1 we have air, which offers considerably less resistance than the water, and we can imagine, following the same line of argument, that the force would be ejected here, and finally exhaust itself, possibly by this ejection against gravity from the surface water. But we are reminded that force does not exist except in accompanying gravitating matter, and that in this case it has manifold resistance by its adhesion as previously shown, so that it will simply swell up under the compression caused by the projectile force and overflow.

d. The above conditions are given for projectile fluids only, and do not relate to frictional movements of solids, that intrude no new mobile matter, the conditions of which will be hereafter taken.

CHAPTER IV.

TACT OF FLUIDS UPON SOLIDS AND UPON PARTS OF
N OR OTHER SYSTEMS. PRINCIPLES OF ROLLING
IN FLUIDS MOVING UPON LATERAL RESISTANCES.

iples of Motive Contact of any Material System

s of displacement in constant contact of one mass or
atter, upon or about another, can take place only upon
efinite mechanical principles.

ss, unit, or part of any body may slip or glide upon any
part. This it may do either in a straight plane, lineal
ection of motion, or upon any curve of regular radius
it is free to move tangentially. In gliding motions the

is free to move upon its *centre of inertia*, or by some mode of *jointing* in a part of the system at a position *normal to the plane of contact.* Or that both units of the system be in like manner free to move on a joint, or free part or parts.

d. The above defined principles of motion are common in mechanics, and are known as motions of *sliding* and of *rolling* contact. It having been clearly demonstrated that the friction of sliding contact, however smooth or perfect the planes of motion may be, will be much more frictional than any system of rolling contact for the same weight of matter displaced; and for this reason also to resist the strain by friction of sliding, all parts of a sliding system, as just stated, must be made perfectly rigid. This rigidity in mechanics is effected by the hardness or perfect cohesion of the matter of which the sliding surfaces are formed, by the smoothness of the parts, and by the perfection of fixing at points in and near the area of contact; as we find that in any material mobile system of two bodies in motive contact, if one of these bodies by defect of internal cohesion and of fixing, is so far free that it can move upon any point not in the plane of contact in all directions, or in one direction only perpendicular to the plane of motion, it will then make under displacement *rolling contact* tangentially to the radius of such axis, joint, or free part of the system. The mode of fixing for the conditions given above may be by the action of gravitation upon the body, by inertia of mass, by cohesion, or by mechanical means.

e. From the conditions of the above mechanical principles, which are clearly applicable to every mobile system, it would appear to be certain that *slipping* or *gliding* motion could in no case be rigidly applied to the motion of contact of a free mobile system of matter of any kind, or of a fluid in motion upon any material body whatever, as a fluid mass must be conceived to be matter possessed of perfect mechanical mobility, which is equal to an *infinite number of joints* or free parts in its system. The only conditions under which the principles of mechanics could possibly permit any elements of gliding contact in a fluid would be in cases in which the rolling contact of the jointed parts were confined to so close an area that the general adhesion of the fluid to a solid, and cohesion to its own
r, would place the fluid under such molecular restraint, that
uld be approximately equivalent to a system of mechanical

is no doubt in my mind, that by taking some very superances of the facility of separation of the parts of a fluid neglecting the consideration of a fluid as a cohesive bile system of jointed matter, the conditions of which pably evident independent of all theories of fluid matter, een taken for granted that no mechanical friction-saving ld be necessary to be considered to overcome liquid n such light, lateral resistances have been heretofore o be actually overcome by separating or gliding motions ermed, and formulæ built upon this principle without tion of quite arbitrary functions have signally failed.

onsider the perfect structural solidity of water as we nder compression, and upon this condition of solidity ve any possible condition of molecular aggregation that its cohesive system, we must conclude that if a frictional pping is possible in such a system, there must be present ar or planic molecular forms of primitive aggregation upporting the rigid planes necessary for this form of of this we have not the most remote evidence. Other- e be in the construction of the fluid any system of free act with its separate parts, which the very nature of a s to indicate that there must be; then we must imagine g would be very improbable, as any form of rolling *i.* Taking the whole of the above in the very narrowest philosophical light, we are bound to imagine a fluid a more mobile system of matter than any machine possible of human construction, and in the machine we find that the mechanic in its construction, to save friction, will avoid sliding surfaces where possible, unless he has much surplus power, and that even when using sliding surfaces where absolutely necessary, he will make use of a fluid that is a mobile system of matter, or *lubricant* as it is termed, between his necessary sliding planes, so that what we absolutely find in mechanics generally, is that sliding planes of motion are reduced to as small an area as possible, as in the wheel-work in machinery. This principle we see followed also in road and railway carriages, where the friction of progression by contact with the earth is thrown upon the less area of the axles of the wheels, which axles are reduced to the smallest possible frictional area consistent with the necessary strength for the work to be performed by them, and this friction is again reduced by the intervention of the most perfectly mobile fluid system or lubricant, possessing the smallest chemical force of adhesion, that can be found capable of intruding itself between the sliding parts.

j. The facility with which rolling contact can occur in a mobile system will depend upon the direction of impulse to the axis joints or mobile parts. Thus if the resistances are directly in front of such axis, they will produce a pressure, so that it will be only in proportion that the material system or fluid can be directed aside to oblique impulse that rolling contact will be possible. On the other hand, resistances that are placed laterally, or that act perpendicularly to the plane of motion, will be those in which a mobile system will make rolling contact with the least possible friction.

k. A great principle *negative* to slipping contact of fluids was discovered by Venturi, in the evidence he produces of the lateral communication of motion to fluids, in his important work before alluded to; although he does not offer any theoretical system of rolling contact, as I intend to do; still he demonstrates in many ways the evident cohesive forces of liquids, which by itself would render slipping contact very frictional, if *possible*, in a mobile system of matter (35 prop. *g*).

Perhaps I should notice upon this subject, what is otherwise that motions of rolling and slipping contact may be com- one system, as, for instance, in certain grinding machines,

locity of the periphery of one of the rollers is made by
neans greater than another against which it slips and
h cases the friction is nearly as the amount of slipping
at this may be taken mechanically as a sliding system.
great refinement is required, then its components may
arately.

Cases of Rolling Contact in a Material System.

may be displaced by rolling contact upon another
ways, which are both applicable to fluid motions.
may itself form the roller and be of globular or cylin-
nular form. 2. The body displaced may be a plane
on a number of such globes or cylinders or rings which
riction-savers to the motive plane. It will be conveni-
consider the principles of these motions before offering
on the principles of rolling contact to be applied to the
of fluid matter.

first place, for the conditions of a free roller, it may be
ically that perfect rolling motions produce very small
e planes of contact, as in this motion, the separate parts
f the roller are balanced by other parts, so that all parts
stant equilibrium. The equally distant balanced parts
d to fall consecutively upon the contact plane and

tact we have only to imagine a level plane and a roller to be infinitely smooth and indeflectible, and the roller to be infinitely true in all its circumferential parts. Then any impressed movement upon the roller, be it a cylinder, globe, or ring, that can overcome the inertia of its mass to cause it to roll, in the first instance, will be theoretically a *constant force*, gravitation being assumed to act equally about the axis, and normal to the plane of motion.

d. For the conditions under which a plane may be displaced by the intervention of such free rollers as are described above, if there are more than two rollers, the mobile plane must be of necessity parallel to the plane on which it rests, and between which the rollers are interposed. Then if the two planes are perfectly smooth and indeflectible, and the rollers perfect cylinders or spheres, the system being without gravitation or in equal potential of gravitation, during the motive displacement of its free plane; and we now impress this motive plane with any force in the direction of its free motion, that is sufficient in the first place to overcome its inertia and that of the rollers, this force, as far as the mechanical conditions are concerned, will be a *constant force.*

e. It is quite certain that we cannot attain the perfect conditions assumed in the above paragraph, with known material and by human skill, but such a system may be experimentally shown, with sufficient freedom to support theory, by a plane of plate-glass supported upon another like plane by three equal metal globes as perfect as can be made in a turning-lathe. With this experimental apparatus it may be shown that when the inertia of the system is overcome a very small force will be sufficient to continue the motion to the extent of the area of the plane, or as far as this is in gravitation equilibrium in the system.

f. As soon as we come to investigate the principles of rolling contact in a fluid, these principles become complicated with functions of lateral resistance, head resistance, and traction. I will, however, endeavour in this chapter to consider the conditions of rolling contact under aspects as simple as I am able for the demonstration of this principle of motion only, to show simply that this form of motion is clearly applicable to fluids. I will take further conditions afterwards, where we may more clearly estimate the influence of direction of motive forces, by deflections under head resistances in the next chapter, and other conditions of circumscribing lateral resistances further on.

s of Rolling Contact of Fluids.

)SITION: *If a free mass of fluid flow upon or against a stance, the motive contact will engender a system of rota- hole or in the near parts of the fluid mass, which rotation mately resemble the motion of a free roller on a smooth*

sumed that we admit the general principle of adhesion olids, and of cohesion of fluids intermolecularly, as previ- ed, and as shown clearly in the modes of lateral commu- otion given by Venturi (35 prop. *g*, page 119), by which notion moves near quiescent parts in its own direction. sume the fluid as being adhesive to a solid, and in itself may conclude that a flowing fluid moving against a will have less flowing velocity near the solid, where it greater resistance from its adhesion, than at a greater m it, where it experiences less influence of resistance, continued through the system. This higher velocity distant part of the flowing fluid will necessitate the ndition that one part of the flowing fluid mass must he other part, either by revolution upon the part in hat some general principle of molecular separation must ghout every part of the system for unequal parallel in fluids, amount to many hundreds; indeed, I have found so few instances of fluid contact to occur in which this principle cannot be observed, if tested by making the fluid motion visible, that I have not been able to find any real case of doubt. I will offer a few simple cases.

c. While I am writing there is a chimney at the house opposite (a copper flue possibly) pouring out smoke very profusely, and the smoke-clouds are being carried away slowly by a gentle breeze. There can be no doubt that the smoke, as it feels the resistance of the relatively static air outside its visible column, rolls over in its upward motion upon contact with the surrounding air, as the motive force of the lighter smoke is constantly retarded at its outward parts. It is quite observable that it curls outwards in detached consecutive rolls. In this case the rolls appear to come out at equal intervals of time, the direct motion being most probably retarded by consecutive adhesions at points by irregular contact upon the chimney. The slowness and regularity of the motions permit the principles of rolling contact upon the air to be made clearly manifest.

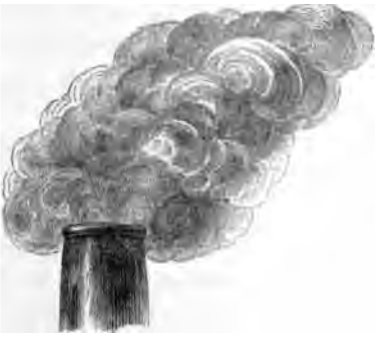


Fig. 52.—Ex. Rolling Contact of Fumes on Air.

This phenomenon may also be observed in smoke issuing from a funnel of a steam-boat; this I have watched with a telescope as rolling by contact for many miles upon the still air, after issue from the funnel. It may also be seen in smoke or steam issuing from a locomotive boiler on a railway.

For another illustration nothing can exhibit this beautiful
nenon of the nearly frictionless rolling contact of fluids better
mple observation that we may make any day, of the mode
urrent of hot air and steam rises from a vessel of hot

ater into the quiescent air, as it may be seen in any
st the light in cold weather. The vapour as it rises,
comes visible, giving the forms of the vapour motion
of condensation. As we watch the steam rise it rolls
he still air, which forms its surface of resistance,
the small velocity of its rising current in its almost
th. It thereby becomes deflected into rolls and scrolls.
the resistance of the air above is observable in its
rning the upward current from direct upward continu-
will hereafter consider. The same forms of rolls and
ible in the clouds upon any windy day, or on a still
re are currents passing above, and it is only in excep-
at other forms are noticeable. In warm air charged with
ur as it is rising it encounters the cold strata, projects
e against it, intrudes its mass, which becomes visible
t, and the vapour is set in cloud, in the form that was
to intrude its small projectile force by its less specific
he quiescent air above. It is possible that the cloud is
form of matter, also one of greater specific gravity, than
which it is formed, so that the first visible form is fixed
egree static in gravitation equilibrium, and afterwards
rm. If the cloud forms which we term a *mackerel sky*

f. In the August of 1873 I was descending Mount Pilatus to Alpnach by Lucerne, in Switzerland, when I passed through a cloud that extended to considerable depth for half a mile or so. The cloud was moving slowly downwards in the direction I was going, so that by stepping out a little I was soon through it. When I was quite clear of it it stood up with majestic, distinct rounded outline to a height of 40 feet or more on the front edge. I had the curiosity to run beyond it and watch its motion in flowing towards me. I could see in this instance, that it made rolling contact upon every plane, and rolled over leisurely as it advanced. Permitting the cloud again to reach me, I could see within the cloud the direction of the motions of its parts clearly visible by the small differences of tint from density, as its parts were rolling in equilibrium of the general mass system, by which the forward parts appeared to fall to the ground. I have repeated the effects of this experiment by pouring smoke on a smooth inclined wet surface.

g. With liquids, the continuity of adhesion of surface, will under the conditions of separate rolling systems of motion, be less apparent and less general. However, the following experimental evidence of the principle may be offered. Having a tank 4 feet in length, 8 inches in depth, and 1½ inch in width, with glass sides. In the centre of each end of this, I placed a half-inch pipe for the admission and egress of the liquids. Having filled the lower part with a clear saturated solution of common salt, and the upper part with clear water, I coloured some water of the same temperature with aniline dye. In this case the water as it was projected along the plane showed the evidence of division into separate rolling systems, which moved over the plane formed by the salt water, establishing particularly, a rotary system near the entrance where the supply of water was constant.

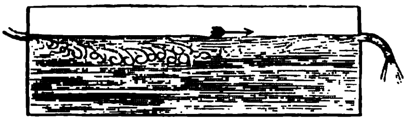


Fig. 53.—Ex. Rolling Contact on Water.

47. PROPOSITION: *If a flowing fluid is held in the lineal direction flowing force by its general cohesion, and by gravitation, so that ral areas of the fluid are compelled to flow parallel to any plane*

. *The flowing force will in this case, as in the last pro-*
l to engender a motion of rotation in the lateral parts of
so that the central areas in relation to the lateral parts,
y nearly equivalent mechanical motion to that of a true
ree cylindrical rollers, over or past another plane of resist-

conceive such a system of motion for fluids, as that
4 art. *e*, the exterior line of a current, assuming roll-
upon all surfaces, would continue its motion parallel
es, and maintain the highest velocity in the most free
So far, this would very conveniently represent one of
s of rolling contact, but as we know there are no such
in the relative parts, or of their motions in a flowing
of planes and rollers, we must conceive that this cannot
a principle of motion of which we have to modify the
o meet actual cases. Thus, in the first instance, in
o apply the above principles to a flowing fluid, it is not
a perfectly detached mobile system of many joints,
onceive a fluid to be, to assume that the rolling contact
rely by rigid rollers or their equivalents, formed of the
ediate motive parts, represented by any exact interven-
ce, or to extend to such diameter as will reach from the

the larger area. Thus in considering this conception of rollers theoretically, extending over the distance from the central force to the planes of resistance, we might in certain cases, take it that less friction would be incurred by assuming the motive parts to be affected consecutively in almost infinitely close parallels, which might be represented by intermolecular rolling planes, in which, although the separate molecular friction might be somewhat greater in the near parts, the inertia of the fluid mass, necessary to be overcome for the general motion would be proportionally less. Under these conditions, taking the rolling contact as separately applicable as friction-saving motion between every filament of a running stream, assuming such filaments possible, and extending this filamentous and rolling system to the banks or bottom of any stream, we may on these principles consider the conditional motions that would occur. We will take for illustration the conditions of one parallel plane of water, or a filament which we may consider as composed of globular molecules, placed at one-fourth the width of a stream running between parallel banks, by which the flowing force is resisted. This line of one-fourth that we have selected would be at mid distance between the centre, which we will assume is the most free part of the stream, and the parallel banks which form planes of perfect resistance. Now suppose, as previously discussed, that all parts of the flowing system are influenced by adhesion and cohesion. There would then be on one side of the line we have taken, the more free central force of the current, flowing and carrying forward the near water by lateral cohesion with a certain consecutive velocity, and there would be on the bank side of our selected parallel, the influence of the resistance of the bank, which of itself would have no velocity. This would, therefore, be retarding the motion that the central current would otherwise engender about our imaginary molecular plane. Now as both of these forces would be in activity simultaneously, supposing the principles of cohesion to proceed in water with some equal force for indefinite distance; then any separate mass of the water at the line we have imagined, or any free molecule, would be *constantly moved by a motion of rotation proportional to the difference of velocity of the two contiguous parallel planes near to it*,—in fact, acting as a *roller* between two planes of unequal tive velocity, these planes themselves being assumed to be d of like rollers.

cing the above construction to be the actual, by this we

nechanical principles very little from those given in the
ınd in our earlier conceptions in the previous proposi-
nay find that if we theoretically extend the diameter of
oarts in the molecular line we have taken, as we may
nuing the principles of lineal velocities proportionally
ir of very close parallel planes to planes more distant
en, instead of the single molecular series of rollers pre-
ined, the interventions of small masses which act equally
ced between these more distant planes, and these rollers
ed by the influences of the two lateral unequal veloci-
now conceive the planes to possess. If we further
principle of parallel velocities from the centre of the
am to the static banks, the same would occur in prin-
ore we might theoretically equally well represent mole-
n close planes, or masses, or systems of rollers between
planes with like effect. In all cases one of such planes
or past the other would give uniformly the centre of the
molecular mass, disc, or space that we take for a unit
planes of motion a moving force equal to half the velo-
moving central plane; or as the equation of velocity
motive tangent and the tangent of resistance to the
s. We shall see, however, hereafter that this system will

with the current, appearing to constantly roll upon the quiescent water towards the bank of the stream, which reacted upon it, although it was at a distance from the surface of resistance. In this experiment the rolling motion of the disc was not so great as though it rolled upon a solid surface, but the influence of the resistance was sufficiently clear, to be visible by the direction of motion induced; it could clearly in no case produce as great rotational velocity as one of direct contact, unless its centre were the *only axis* or joint of the system. The axes of the liquid system and their numbers of influences being as before shown to be practically infinite.

e. It is very possible that the motion induced in the molecules of lubricants, moving in close planes, in machinery may represent the principles of this proposition more nearly than the motions of any more free fluids, which would be subject to greater interferences, as further propositions will show.

47. PROPOSITION: *That upon principles of rolling contact in a fluid moving upon a plane of resistance the distant separate parts of the fluid will be influenced to move at a velocity proportional, in reference to other parts, as the radius of distance from the resistance.*

a. By the last proposition every motive molecular plane that is more resisted than another, becomes a plane of resistance to any other motive plane endowed with greater velocity, so that by the above conditions in the motion of parts of a fluid, we have tendencies to radial velocities about all lateral places of resistance, whether these are motive or quiescent.

b. For the motion of two planes, between which I imagined a liquid to act as a series of perfect rollers, we may observe, that although these imaginary rollers were assumed necessary for the continuity of motion of one mechanical plane over the other, that at any particular instant of time, only one of the diameters of the rollers would be in active service, that by this, so far as the smallest time of motion was concerned, we should need only one infinitely thin plane through the axis of the roller to be active extending from plane to plane of the parallel planes imagined. In fact that, if instead of our three perfect globes suggested for the continuity of motion of the rolling plane, as a mechanical principle, in the case posed (44, art. *c*), we had three thin vertical rods of equal diameter, would act in every way the same, for the movement of the horizontally for an infinitely small distance, and space of time.

he above principles we might consider the entire fluid planes of motion, or of motion and rest, to be repre-ii at every point extending horizontally to the planes r if we could extend these principles to the axis of a g the resistance of the banks and the bottom of the entral course might be imagined almost frictionless. ammatically expressed in Fig. 55, where portions of

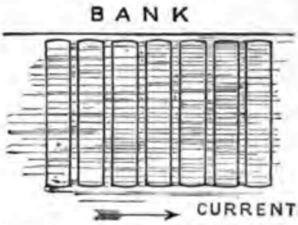


Fig. 55.—Diagram—Rolling Contact of Stream (hypothetical).

al rollers are represented between the current and the ream.

in elements of the principles discussed above are active, d from the velocities of single waves, to be hereafter d the same principles may be inferred from the velo-al areas in wide flowing streams resting upon deep plane. This may be represented roughly in principle as in the diagram below, where the lower curls are put to represent rolling contact upon a resting surface; the radii are shown to increase in

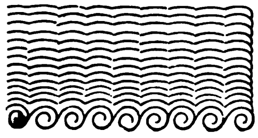


Fig. 56.—Diagram—Rolling Contact under Equal Gravitation.

segments continuing of equal length of chord of arc to the upper free surface, where they form a motive nearly level plane.

f. The difficulties that would be most apparent in such a system are that by the continuity of adhesion to the radii of the rollers, these rollers could not act entirely as friction savers, without considerable intermolecular friction of slipping for small distances upon themselves; and this slipping motion our theory of rolling contact will not admit, if there be by any possible means a less frictional motive course. It is therefore necessary that some modification of this principle should exist, for this to be the mode of motion of a free fluid. Nevertheless, the reality of the principle of motion in certain cases, I shall be able hereafter to better demonstrate by observation of the borders of certain frictional currents; in this matter, however, every motion of the kind is complicated with components of head resistances which I have yet to consider.

48. PROPOSITION: *That by the principles of rolling contact of fluids moving upon lateral resistances, free currents will have a tendency to be constantly directed towards the planes of resistance, with velocities which are as the directive forces of possible tangential motions of rolling contact, normal to all the points of resistance in an infinitely jointed molecular system.*

a. Taking the conditions of radial velocities offered in the last proposition as entailing a certain amount of frictional motion, I will in this proposition consider the conditions under which the same principles of motion may be preserved under less frictionless forms, by loss of a certain volume of the direct flowing force.

b. If we were to take, instead of radial lines, as a part of a motive roller, that I have assumed to extend from the motive to the rest-part, of a fluid system—a larger portion of the assumed roller,

ce, the forward part of its semicircumference, we could
in this case that such a system would be motive in the
s the radii before considered. The system would be
the same time less rigid, and as we shall find, more
a motive jointed system. Such a system is shown by
below.

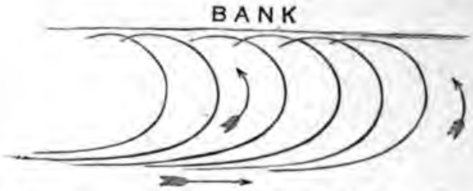


Fig. 57.—Diagram—Proposed Semicylindrical System.

system we could nevertheless imagine that it would
fect, that the separate semicylinders proposed would
structed of equal parallel quantities of matter, and
supposing the mobility of the part of the fluid to supply
he mass motive forces of the cylinders would be greater
n of the perimeter than another, and the mass velocity
equal in the parts, which would make the motion fric-
her, that although these semicylinders would be com-

plete the inequality of mass in parts of the semicylindrical system. In this case the motion may be conceived to be continuous at the expense of a certain disintegration of the volume of flowing fluid, which would, by the conditions given, be deflected into the semicylindrical system of motion, the principle of which is indicated by the diagram above.

e. To demonstrate the above form of motion mechanically we will assume a lineal or filamentous system of stratum for our current, which may be represented by a low pile of smooth paper or ribbons. If we place this pile of paper or ribbons upon a smooth surface, as, for instance, a sheet of glass, and place the glass at a slight inclination, the paper or ribbons would rest perfectly static upon this, as to run down the incline they would have to slide upon each other, or upon the glass. But if we now take the proposed stratum of ribbons, that may be of, say, five to ten separate pieces, and turn down the front ends over towards the lower part of the incline, and bend them under the other forward parts of the stratum by a curve that produces a semicylindrical arc in front, we shall now find that the stratum of smooth paper or ribbons will be rendered motive, and constantly turn in series, separately one by one at the bend, until the stratum is again extended the entire length of the pieces at a position lower down the plane. When this motion is complete, the stratum taken will be left quiescently upon the plane, and move no more, the papers or ribbons being now piled in *reverse order* to their first position. It will be seen that, in this operation we transfer the potential force of gravitation acting upon the upper papers or ribbons in the pile to a lower position of equilibrium, in which each piece will be now held upon the plane surface by the resistance of its adhesion, so that it does not move further by the potential force of the inclination against the amount of friction that would be necessarily present in a slipping motion.

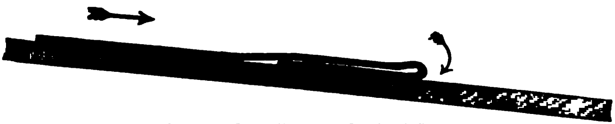


Fig. 59.—Ex. Ribbon on Inclined Plane.

f. We may perform this experiment in a more simple manner single smooth band of paper or of satin ribbon upon a smooth e, as that of a sheet of glass. This band or ribbon if started manner to that described above for the stratum of a bend in front towards the lower end of the incline, long the plane and come to rest by turning gradually front edge without great friction upon the surface upon rwards reposes. This arrangement is represented in the ove.

s principle of motion, as a rough demonstrative ex- may conceive the mode of motion by which streams isintegration of their volumes and forces, by resistances *s* of their currents only, to insure the nearly frictionless rolling contact for their central masses. Wherein the sive force of the interior mass or main body of the cur- held entire, and move at approximately equal velocity area without material deflection past lateral resistance, portion only to the flowing force static on the plane of r by inducing within it, a small minus velocity by the of rotation, in which the deflection of the central force, rcomes the friction of lateral resistance by a small loss e. This principle may be evident in oceanic currents ain a certain velocity nearly intact, although the sectional current gradually decreases. It will also be evident in s of transverse parts of streams. I will endeavour to and left a wet line upon the paper. My next object in following this experiment was to discover exactly what portion of the running stream wetted the paper, for it was quite clear that if the paper was wetted by the lower surface of the water only, it must be by a slipping motion. Therefore, before recommencing the experiment I provided myself with an ordinary culinary pepper-box so as to follow, by the floating particles, the surface motions of the stream particularly. Now taking another clean sheet of paper and placing it as before on the wet inclined slip of glass, I again permitted the jet to flow from the can on the upper part of the plane as before, but when the pool was formed and just ready to run down the incline, I instantly dusted it with the pepper, which, being light, rested entirely upon the surface of the pool. Now watching its motion I found that each floating particle as it was carried along the stream ran with greater general velocity at the surface than the average velocity of the entire stream, so that particles arrived consecutively at the front of it. That as soon as a particle arrived at this point it instantly turned the beaded forward edge of the stream, and then lay itself quietly upon the surface of the paper, *so that the pepper that was dusted over the surface of the water in the pool took an entirely reverse position, having moved from the top to the bottom, showing thereby an entire rotation of the current at its head, or most free part.*

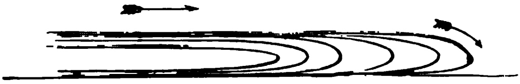


Fig. 60.—Ex. Flowing Stream.

i. In this experiment the pepper on the flowing stream is transferred from the top to the bottom surface by the flowing force, as our strata of paper or ribbon were shown to be. The same principle evidently exists without the dust upon the surface, so that the water alone would leave a wet streak of disintegrated water from the surface of the flowing stream. I presume this to be a visible condition of a principle that is made evident in the above experiment by the adhesion of the liquid to the solid surface.

j. We also find evidence of the same mode of motion in the ex- iment of the floating disk offered 46 prop. *d,* in a condition not iously mentioned, that the disk will be found not only to rotate ore shown upon its axis of inertia by the differences of velocity parts of the stream, but it will be *drifted towards the borders*

t. A friend to whom I mentioned this principle of fluid
is very fond of jack fishing, tells me that he has often
troubled with this phenomenon just described, having
he stream not only rotates his float and twists his line,
arries his float constantly towards the edge of the run-
and he tells me he has no doubt that every jack fisher
ticed this, and perhaps, like himself, have been puzzled
he cause.

OSITION: *That upon principles of rolling contact, the*
liquid flowing down an inclined plane, will be for a dis-
to the chord of an arc described upon the plane with a
depth of the flowing liquid as the chord of the supple-
arc from which twice the angle of inclination from its
n.

A′ represent an inclined plane of resistance upon which a liquid flows.

Let B B′ be the surface of the liquid flowing down this plane, of a depth equal to the distance between the parallels A A′ and B B′.

Let C be a centre upon the plane taken to be any point of contact of the flowing *b.* In the above scheme the liquid is assumed to be under no molecular restraint, but to be taken as a perfectly free molecular or infinitely jointed system as that proposed 6 prop., with no adhesion to the plane of resistance. It is, however, certain that a liquid has an adhesive force upon every plane of resistance, and that this will retard the velocity proposed above in a certain uniform ratio. It is possible that this will form a minus constant quantity equal to the adhesion of the liquid to a free surface, per area of the frictional surface. There will be present also a small component of restraint from molecular friction, that will be inversely proportional to the square of the distance from the surface of contact for all parts.

c. This proposition must be held to be purely theoretical, founded upon principles of rolling contact only as given in previous propositions, but of which I regret that I have had no time for research or experimental investigation for actual velocities under the conditions here proposed.

50. PROPOSITION: *Currents of constantly flowing fluids moving past quiescent lateral free spaces, or in bays in any direction will form rotational systems in the fluid in such spaces or bays, which will move upon the centres of inertia of the lateral masses moved, so that the circumferential movements of the more free lateral parts will approach the flowing velocity of the current by which they are moved tangentially, and this direction of motion will save a large part of the friction of the resistance, to the cohesion of the fluid upon the surfaces against which it presses.*

a. This proposition offers the means by which the friction upon a lateral open fluid space exposed to the action of a current will be much less than the friction of near solid resistance. The proposition is not only important in the consideration of the mode of projection of oceanic currents and the flow of rivers past bays, but is applicable to over currents in deep water also. The mechanical principle of this form of motion may be conceived by the following.

b. If we take again the conditions offered of a perfectly true cylindrical roller between perfectly smooth level planes, proposed 44 art. *c*, for demonstration of a means by which a nearly frictionless continuous motion might be produced in a plane under the equal influ- of gravitation, we find that where motion is produced in plane and the rollers, this will be a theoretically constant Therefore, if we take one of these rollers, and if the plane ioves over it, with uniform velocity equal to the induced ie periphery of the roller, there would be no friction in passing over this roller. In the present proposition we r the central flowing liquid of a current as the motive he quiescent lateral system as the roller.

ndeavour to take conditions of the liquid roller based ctionless motion which I have assumed to be possible, or the present all conditions necessary for the formaablishment of the liquid roller itself, or assuming only iotion that the general infinitely jointed system of the

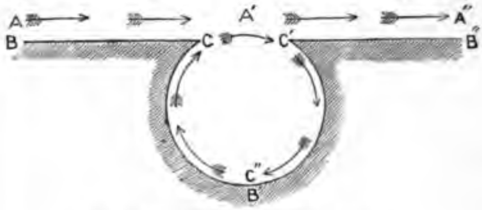


Fig. 62.—Diagram of Lateral Rotation.

ts by motions of accommodation, then the entire effect ler upon the central current will be to remove the fricsion of the solid lateral plane, by inducing a motion of this case, if the friction of rotation of the lateral mass was *greater* than the friction of one part of the fluid passing the other in the plane B to B′, this space C C′ C″ would not be rotated. But if the friction were less by such rotation it would be rotated, as the tangential action would be equal in each case upon the lateral mass, whether it were rotated or not.

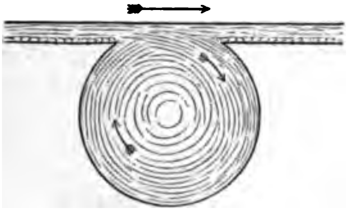


Fig. 63.—Ex. Observation of Lateral Rotation.

e. For evidence of the above being a principle of fluid motion the following experimental evidence may be offered:—If we allow a stream to flow through a uniform channel for a certain distance, and then enlarge the channel upon one side or the other horizontally or vertically, as in the diagram above, we find that as soon as the water is free from the near resistance of the narrow part of the channel, to pass the open part, it rotates the curvilinear part as shown in the diagram. This may be made very palpable by particles of saw-dust, or other light bodies of about the same specific gravity as the water, being placed upon it or in it. The same principle of motion may be noticed in any little pool by a flowing river-course, in the motive direction of particles of scum or other matter that may be floating on the river surface. By careful examination a reverse action on the borders of the current, in the lateral space, may be also clearly seen, active as a friction-saving motion to this rotation; but I shall be able to offer much more certain illustrations of this after I have discussed some further principles. In the illustration above I have simply shown a lateral circle rotated. This will occur in any form of free space for a *part* of the same; therefore it is here used diagrammatically only. For our present purpose for the rotation, we may take it that all slow motions in fluids are less frictional than faster ones relatively to the velocities of the moving parts, so that if motive lines are extended, system will become less frictional. This will possibly, for one e due to the sum of the elastic forces disturbed, which react to brium, but not generally in the direction to increase the e motive part, or at the instant of impression. In this astic system resists motion, until the impression of the nded in its mass, so that it may overcome the inertia of t of the mass than that impressed, by smaller motions buted, the separate parts being disturbed less from their quilibrium, and the elastic tension being less in any part . Further, an infinitely jointed system, with any polar ever in the joints (10 prop.), will be proportionally free as the radius of motion is increased.

SITION: *That a flowing fluid moving upon an open area ike fluid, will have its exterior flowing lines deflected into fluid by lateral cohesion, until the curves of deflection of uid circumscribe a certain area, the constantly increasing ll describe by this cause spiral lines which will move entre of inertia of a rolling system, formed by the lateral l the resistance in the deflected current equals the flowing oint of impression. The constant flow after this will pass rotary system established.*

ving force moves coherent to a lateral infinitely jointed , it will at first move the nearest molecules or infinitely finger. We will suppose this mobile volute to retain a centre upon which the mobile matter coils. The volute may be either standing alone on this smooth plane or be contiguous to another plane above it. Suppose that the thin sheet of mobile material that forms the volute is brought up by surrounding matter, or is otherwise supported, and that it is constantly in equilibrium at the upper surface of the roller, and is mobile to the impression of any small force, and that the volute only is subject to the force of gravitation; then it would continue to roll for an infinite period without friction if the band of which it was formed was of infinite length, by the action of gravitation only, which would supply the small necessary force upon the forward portion, as the following diagram will show.

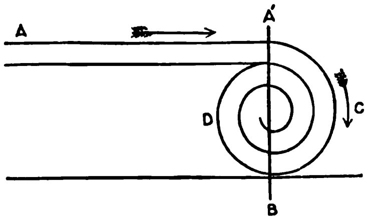


Fig. 64.—Diagram—Spiral Action.

d. Let the lineal plane A A', Fig. 64, be perfectly mobile and be supported without excess of gravitation, as in a flowing stream, and be without inertia or of such motive inertia that it will not retard the action of the volute. Let B be a perfectly level plane, and the centre of the volute or first roll of the coil that continues to roll upon an axis central to A' B, and let gravitation act upon this volute only. Then will the predominance of matter on the forward side of the axis A' B towards C cause the volute to constantly roll up in the direction of the arrow at C, by the greater action of gravitation on the forward side supplying the necessary force.

e. For the condition of fluid projection under tangential action we may omit the force of gravitation, which is here used to demonstrate the smallness of force necessary to produce the continuity of an involuting system. If we arrange the circumstances otherwise, as for instance that a current flowing from A to A' carries the band A' forward towards the volute with any small constant force, so the flowing force that forms the supply is given constantly to

ıis would then cause it to continue to rotate and enlarge,
m of area and other circumstances permitted.

ıy further consider that if the rotary system were not
ı a frictionless centre of inertia, but upon a plane, that
supply of the current A A′ would maintain a friction-
infinitely.

, if there was resistance at C, Fig. 64, to the flowing force,
nly increase its deflection into the volute, and maintain
ıg system static in space. This might occur with very
if the system of fluid that formed the volute were in
librium.

ıe above diagram, we were to reverse the volute, sup-
tly mobile, moving on a perfect plane, and permit its
roll instead of roll up, it would continue to unroll
ite time if the plane were of infinite length, as in
tance, or finally to the end of the coil if of finite

fluids, suppose the flowing force to be a small constant,
all loss of its lateral matter, it could form volutes in
aces until a rotary system was formed of the mass in
nt spaces, and when such mass was formed the original
wing fluid would flow forward by moving tangentially

proposition, so that I need not in this case offer more than experimental evidence.

b. A trough that I made for other experiments, twenty feet long and eleven inches wide and of the same depth, was placed horizontally. At one end of this trough a false bottom was fixed, extending for about eight feet, this being of the same width as the trough. The false bottom rested upon the true bottom, one end being elevated and fixed upon the end of the trough, at a height of about six inches. In this manner it formed an inclined plane, as shown in the illustration. Water was poured into this trough to a depth of about five inches on the level part, and the experiment to be followed was to project a certain volume of water up the incline. For this purpose I took a piece of board of the width of the trough, and of sufficient length to hold conveniently in my hands, and placed this at first upright against the vertical end of the trough; now by moving it towards the inclined plane, for a foot or so, a wave was formed, which moved forward over the surface and finally impressed its force upon the plane. This wave, as it met the increased resistance, was gradually increased in height, and it showed by its more rounded form that the rolling principle of contact was becoming outwardly visible. As the wave progressed its protuberance increased, until it reached a certain point up the plane, where the projection above the general surface equalled the depth of water beneath the average surface. At this point, for an instant of time, a complete rolling volute was produced, whose motion was clearly visible as the water broke in its fall over the upper part of the rounded wave.

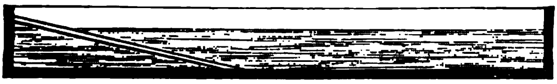


Fig. 65.—Section of Long Trough.

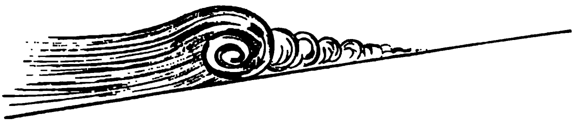


Fig. 66.—Diagram—Liquid Rolling on Incline Plane.

The water, at the instant of the formation of the perfect roller volute, will be pushing water in front, which forms sometimes

f rounded projections or loops, which are not a part of
demonstrated by this proposition, but are due to minor
ems in which there are present evidences of other motive
not yet considered.

e above experiment it will be clearly seen that the pro-
the involuted system above the surface is wholly due to
t resistance of the plane, and is exactly equivalent in
of motion to the cases previously considered, where the
deflectible liquid (last proposition, *i*).

e inflowing of a tide into a bay or estuary an immense
f water enters in a few hours, and the projectile force of
y must be immense. Yet we see the fine sand on the
rface very little disturbed. We may attribute one cause
the adhesion of the water by continuity deep into the
t the principal cause is that the water at no instant
es upon the surface, or even appears to do so, but as we
it rolls gently over and disturbs the land surface very
pt at the extreme edge, where the involuted forms are
by the resistance, and the water makes such irregular
at it moves the light sand and stones as though it were
g motion upon them. Otherwise, if the land surface is
on which the current gently advances, the rotary system,

cule A being attached to a plane or being supported by it. Let the mobility of B about A″ be such that the movement of B upon this mobile attachment to A″ will not engender sufficient *friction* to overcome the inertia of A″ upon A′. Then will a force in the direction shown by the arrow upon B move the molecule B about to its second position B′, shown by a dotted circle, or it will move it round the molecule a greater or less space, according to the strength of the impulse upon B in the direction of the horizontal arrow.

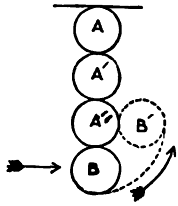


Fig. 67.—Diagram Polar Chain.

c. If there be polar adhesion at the first point of contact of the molecules greater than at other circumferential parts about it, such an adhesion under an impulse upon B as before, would produce a strain upon the whole system, supposed more adhesive through the activity of its polar forces, at all points, and the polar adhesion would move the more distant parts. The same would occur also from adhesion being greater upon the points of contact from any other cause than polarity, as, for instance, by the points of contact being impressed by a weight as that of gravitation to increase adhesion; this matter may be reduced to definite experiment. Thus, if we let a chain hang freely down from a point of support, and then impress a force upon the lowest link, this will by the rigidity of adhesion move consecutive links, and if the force be moderately constant, and not of high velocity, the chain will form a cycloidal arc at the point of greatest motive amplitude by the impressed force at B.

d. If we make a jointed system still more rigid than that of the chain taken above, to represent strong polar forces, the motion, from like impression on the point B, will be entirely upon the most distant joint or point of adhesion A. Thus, if we pile up a stack of single bricks to, say, a yard in height, and impress a moderate force upon the upper brick, sufficient to disturb the general equilibrium, the pile of bricks will fall down by turning upon the axis formed by the *lowest brick*, that is, upon the most distant free joint from the point of impact.

e. By the above conditions we infer that if the cohesive or polar forces of a molecular system of matter are *weak*, that impressed forces will engender motions near the point of impression, but if stronger, to a more distant part, and by the same conditions we assume that one fluid may take less amplitude of rotation

ral resistance than another if its system be less rigid
npression of a force, as oil may possibly take less am-
tation by resistance than water (12 prop.).

SITION: *The amplitudes of motions of rolling contact in
arts of flowing fluids are relative to the velocities of the
s active upon them, but not proportionally so. The mini-
udes being those of very small, and of very great flowing*

e a series of molecules as those shown in Fig. 67, to
cohesive or polar forces attractive upon each other,
sufficient force to destroy the perfect mobility of the
suppose a very small force, as before, impressed in the
the arrow upon B. Now any mode of communication
molecules B and A at the extreme end of the series
ough the other molecules A″ and A′. Therefore if B
sed with an instant force, only just sufficient to overcome
tia, it would move on the nearest free joint towards A″
her, as this force must have a commencement of action
lecular system, which I have assumed to be represented
g system, it would be relatively to the general inertia of
n its first impulse *infinite*, or of the nature of a percus-

move the mobile system upon its *nearest* axis or free point as in the first case *a*. For experimental evidence of this condition, suppose our hanging chain in the last proposition *c* impressed upon its lowest link with a greater force than that previously proposed, or one moving at very great velocity, then the chain would not be deflected into a cycloid at its extreme curvature, by the force, but the curve produced would be more nearly hyperbolic, the impression being normal to the axis of the hyperbola at its vertex. If we in like manner, impressed a force of great velocity upon the pile of single bricks given at *d*, in the last proposition, upon the top brick, this brick would be projected out of the series, but the pile would not otherwise be disturbed as would be the case with an equal force of less velocity.

d. In our further investigation this proposition becomes important when applied to fluids, as in certain cases both weak and intense forces move small areas of contiguous fluid matter, where moderate forces move larger areas and more distant parts, and moderate motions offer proportionally *more resistance*, than either very slow or very rapid ones.

55. **Remarks.**—*a.* By the principles discussed in the several propositions of this chapter, it will be seen that by the rolling contact of fluid matter it is not intended that the *roller*, if we distinguish one part of the fluid as such, should be necessarily of any definite form, although the motions induced will *frequently* give this form by isolation to masses of the fluid, subject to tangential or flowing forces upon these isolated masses. But the propositions are directed to demonstrate that the principles of contact will be such, that motive surfaces of fluids that come in contact with each other, or with solids shall maintain *lineal* or *tangential contact without slipping or gliding*. The resultant motion in the fluid being uniformly in principle that of a rolling motion however modified by exterior conditions. It being demonstrated also that this is the most frictionless motion for an infinitely jointed or fluid body, therefore the motive form which a fluid body will always take upon frictional contact.

b. We may also conceive that if the surrounding conditions are such that motions of rolling contact are not easily, or possibly, induced in the fluid system, in movements upon itself, or upon solids, that the laws of hydrostatic equilibrium, as they are termed, will not in this case be followed. This is the case with the syphon experiment given in 33 prop., where at the time (page 113) I could only discuss the principles of cohesion which evidently hold. But for the conditions of motion by which hydrostatic equilibrium could possibly be established, we have in this case, in some way, to induce rolling contact in two fluids which are of such unequal density, that any motion of rolling contact in the liquid could only be very frictionally continued into the aerial system and vice versâ. So that the whole system resists motion by its cohesive forces simply.

c. The same conditions exist for the needle floating on water given (page 47), for although the water resists by its inert cohesive force, this force would practically disappear as a visible function, if motions of rolling contact could be induced near the needle, which its small force cannot effect on an extensive surface under resistance of local inertia. This is altogether independent of the causes previously shown of the general cohesion of the water and conditions of its surface.

d. If the principles of rolling contact were possible in all cases to be fully developed in the actual motion of fluids, so that they suffered no restraint from interference in their active motive forms in a universally jointed system, as that I propose; a running stream of water would be always projected at some intermediate space between the banks transverse to the direction of the current. This we know as an absolute fact does not occur; as in the stream we have the complication of cohesion, resistance, and motive inertia of all parts of the system, so that all the evidence of rolling contact left observable is that the surface system moves at the higher velocity in the central area, stillness reigns near the banks, and in some cases there is a slow retrograde motion at the banks.

e. As a general fact, motions within fluid systems have commonly little power to complete direct lines of impression of forces, so as to become outwardly evident, either singly or by simple resultants, such as we witness generally with solids. This arises principally from the mobility of their parts having power to engender systems of accommodation for the impressed forces impossible in more rigid matter. The loss of completion of motive effects or forces are often, however, made evident through transference of motive force from particle to particle, with small local displacements, which every fluid permits. The same continuity of impressions being also evident in the principles of disintegration of primitive force by resistant surface, which permits by dis-continuity of a small part of the mass

55 *Remarks.*

small material loss of velocity in a residual part. These principles of motion offer modes of projection of forces, more frictionless for fluids under any movements against resistance, than is possible to be engendered in solid systems moving equal weights. I may further observe, that as rolling motions become restrained, by insufficiency of area to complete their curvilinear paths, the frictional resistances increase, as we find in comparing the resistances of pipes where the fluid motion is cramped, with that of open conduits, where one surface is free. In the one case, the water has no opportunity to move freely upon the resistant surface, or, as it were, to ride upon the motion of rolling contact engendered by the flowing force; in the other case it has this freedom. To this matter I shall return.

f. In this chapter I have only endeavoured to point out principles of motions of rolling contact for fluids upon surfaces of resistance. These may be taken as cases only, for it is quite certain to me that the modes of rolling contact may take place also in other forms than those discussed; but if fluids are considered, as here proposed, as infinitely jointed systems of matter, we may then have every possible mode of motion, and of accommodation for motion in them, and forces impressed will be deflected by every possible directive influence, that offers at any instant of time less motive friction for the volume of matter displaced; some principles of which I will now proceed to consider in relation to head resistances.

CHAPTER V.

OF FLUIDS WITHIN LIKE FLUIDS. PRINCIPLES OF
SISTANCE. PLANES OF FRACTURE AND OF TENSION
GENEOUS SYSTEMS OF MATTER.

ctions within fluids and homogeneous systems of

auses for the motive effects observable in the projection
or upon, like fluids have been considered by Newton
In these cases with little exception the projectile fluid
nceived to impress a like area of resisting fluid, the
ditions of which are discussed in Newton's third law;
ons and the resistances being proportional to the sur-
sed, to the densities of the fluids, and to the squares

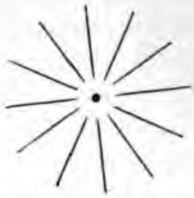
as quite exceptional, that the areas of impression and resistance are equal. Thus, in the cases of oceanic and aerial projections, the areas of impulsion by which currents are formed, are frequently local, whereas the resistances, acting in an extensive cohesive fluid are wide-spread, the motive effects observable being also consistent with this. The same conditions commonly occur in the practice of hydraulics where outlets and inlets are small compared with the bulk of liquid upon which they act; and the same principle will be active in the projection of solids in extensive liquids, as in the projection of ships, as I will endeavour hereafter to show. Upon these considerations it appears to me, that if we obtain a clear conception of the projection of a unit of fluid matter in an extensive fluid, this will establish the *form of fluid projection* that occurs in nearly all the cases that we can imagine to be actual, even as I find in close areas or in pipes. I will therefore endeavour to follow this matter into all the detail that my powers can suggest.

b. For this research it will be convenient in the present chapter to discuss, at first, the conditions of the directive action of surrounding pressures in a fluid system upon one of its particles in equilibrium. Some conditions of this have been already partly discussed in considering the action of directive pressures towards a hole in the bottom of a vessel, 30 prop. *c*, page 94, wherein the position of the hole was taken to be the point of least resistance of the liquid system. In the following propositions I will endeavour to show that similar conditions hold good for the directive pressures that support the *static equilibrium* of a particle in an open fluid, and in further propositions, to show that similar conditions hold for the forces in *motive equilibrium of the particle* also, although by the motions induced, the lateral directive pressures will be deflected according to other conditions to be hereafter considered.

57. PROPOSITION: *That the pressures of surrounding particles in a fluid about any single particle, that secure its equilibrium, are active upon that particle in inverse proportion to the squares of their distances from it.*

a. Let the dot in the centre of the figure above represent a small portion of a liquid that we will term a particle. Let this particle rest upon a free surface, or upon any horizontal plane below the surface. Now, by known laws of hydrostatic pressures, such a particle will be pressed by direct force on every side equally by the

fluid so as to be on no side free to move. In these
t received by one particle is communicated to the next,
e pressure to the next, and so on. The pressures may
assumed to extend by sequential action indefinitely, or



g. 68.—Diagram of Horizontal Pressures about a Particle in a Liquid.

tent of the fluid, and will, by their united forces taken
ontal plane, for instance, secure the horizontal equili-
particle. Now, as this particle receives only the same
ure as any other particle in the fluid, it is quite clear
ssures of other particles, that is, the entire amount of
re that they are able to communicate to the particle
diminish rapidly with the distance, or inversely, as the
ressing particles increase; and as all the pressures of
es, so far as they can affect this special particle taken,
s directed towards it; we may conveniently assume

a particle in a fluid mass from the surface downwards, supposing no special condition for the surface density; then we find that as the particle is supported at the liquid surface against the force of gravitation acting upon it, upheld by all surrounding pressures in the liquid, that take their directive lines towards it: these pressures may therefore be as before, represented by the spaces between the lines radially directed to the particle, as shown in the illustration, Fig. 69, and the pressures being equal to the weight of the particle will insure its vertical equilibrium in equation with the action of gravitation in the system.

c. By the same principle we may conclude that if the particle selected were beneath the surface, as in the illustration, Fig. 70 below, that every surrounding pressure above the particle would also act radially upon it, for such distances as the radii could be assumed to extend as active forces.

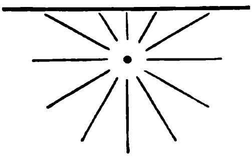


Fig. 70.—Diagram of Pressures about a Particle at a depth in a Liquid.

d. We may also observe that if, instead of taking a particle only of the fluid mass, we had taken a certain unit mass within the fluid, small or large, that the sum of all the surrounding forces or pressures would be equal *per area* to that upon the *surface* of the particle only that we have selected, and that these forces or pressures might effectively be assumed to be directed radially to the unit mass as we previously considered them to be directed to the particle only.

e. We may further observe that these pressures are quantities of force that can be measured exactly by the forces of gravitation, or by the mechanical forces required to resist them; as, for instance, the pressures upon the sides of a ship may be ascertained entire, or those upon any unit of area of its surface below the water line, by well-known hydrostatic laws that are commonly applied to fluid pressures, the conditions of which we need not follow here.

f. In taking areas of surrounding pressures, it might be thought these pressures could equally well in theory be represented by [illegible] directed to the selected particle, whose static conditions

considered. This could *not* be; for, if we gave to the
ny possible parallel dimensions, they would crowd near
and to reach it must be conceived to be reduced to
which is the same as the conditions proposed. Fur-
dial lines, if extended to any great distance with any
l and parallel dimensions, would leave inactive inter-
xistence of which is contrary to known laws of hydro-
erefore, any pressure communicated to a particle is
all the surrounding pressures in the medium, and
total pressure upon the particle is only a unit quantity
to its size in the general system of pressures, yet all
fluid matter may be assumed to impress force upon
in inverse ratio to the square of its distance, as before
This pressure can only be represented for any single
metrically, by a conic area extending from the particle
f a cone at any distance, the pressure at the base being
active pressing force to the resistance at the vertex,
s the equilibrium of the particle.

SITION: *That the movement of a particle in a fluid
ting particles, will cause the compression of a conic area
n front, the deflection of conic areas of lateral particles,*

area of resistance, by compensations, the pressures become hydrostatic pressures derived from direct radial ones. Otherwise, if it were possible for force to proceed in concrete matter in direct lines, a small percussion, defined as it was by Galileo as infinite force, would puncture a hole or produce a dent through any solid mass, however dense, that is, if the force impressed also exceeded the molecular elasticity in the direct line of impression.

b. Under the above conditions nevertheless, we need not suppose the movement of a particle in a fluid for a small distance to require a force to move it much greater than its inertia in *equilibrium*, and even for larger movements, the backward pressures, by the conditions of equilibrium, will have, as hydrodynamic pressures, equivalent value to the forward ones. These backward pressures being also theoretically derived from conic areas of surrounding pressures; they will, however, not be free to act instantly beyond the small value of the static elasticity of the fluid. Therefore all forward movements will cause a certain amount of forward *compression*, which the general system of the fluid must accommodate for the particle to move; and all backward parts of the fluid will receive a certain amount of *rarefaction*, which will act as a force of traction on the following parts, to reduce the amount of the following pressures to equilibrium; if the elastic pressures act inversely equal to the tractional forces which cause the relative rarefactions.

c. For the conditions of direct front or conical resistance' to projectile fluid confined to a small area we have these conditions considered by Newton, for one case, which he takes negatively only, in the second book of the *Principia*, prop. xli.—"*That a pressure is not propagated in direct lines unless the particles lay in these lines.*" As physically considered, fluids are homogeneous; there are no direct lines except such as may be assumed hypothetically. Therefore the proposition taken in a positive sense, as a law of conic resistance, would apparently meet all cases of fluid projections and forms of resistance within the fluid. Upon the above conditions we may take it for granted that, as the first impact of a moving force in a fluid will engender a *compression* in a direct line in front of the impression, and that in the resisting fluid every side of such direct line of resisting matter will be supported by the entire surrounding matter, so also, we can imagine that the cohesive system in front l at once exert its force through a cone of hydrostatic pressure axis is merely a line of superior resistance, *not* the *entire* nd that every circumscribed cone of matter of increasing rom this direct line will offer some resistance (or that pro- the sine of the angle that it takes to the lineal direction ion). Upon this principle we find that any imaginable nic area of resistance, as it extends outwards from the direct forward cone, will take a constantly diminishing resistance with increase of divergence. Therefore if the ter, making a direct projection has such a system that it ivision, the *divided parts will be less resisted upon the e of such a cone than in the direct axial line of it, where ion, therefore the resistance, is greatest.*

rther consider the impressed force as embodied in matter its innate force, after impression, by the first law of ve directly forward over equal spaces in equal times, is resisted or deflected by other forces, we may con- s the *resistance* to impression will be greatest in the axis ard cone impressed, that the impressed force, if free, flected from this superior resistance to any path of less pen to it.

made out the above conditions for the motive equi- particle in a fluid, it was clear to me that in any small of the particle the area of direct head resistance could lateral parts. Thinking that some evidence of this motive form of resistance to direct motion in a homogeneous system might be

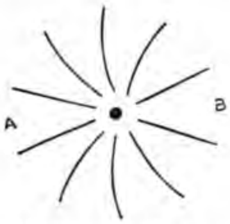


Fig. 71.—Diagram of Resistances to a Moving particle (theoretical).

observed from inertia alone, in equal quantities of matter surrounding a point, I made the following experiment.

g. I drew out a length of leaden wire of about ·06 of an inch in diameter, and cut this into equal lengths of about 2 inches. I placed the ends of all the wires together to form a radiating star, and fixed them in this position by solder, upon the end of a brass rod of 3 inches in length and ·36 of an inch in diameter, so that the rod was perpendicular to the plane of the leaden star. Now placing the star on a smooth plane, with the rod vertical above it, I gave the rod a few taps horizontally with a light hammer near its point of union with the star. The inertia of the lead was thus overcome in

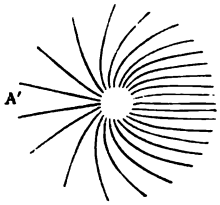


Fig. 72.—Ex. Deflections by the Inertia of Matter about a Moving Point.

a manner that it formed a figure as shown above; in which we may observe that the radial directions in front A′, remain in the same positions as before the experiment, but that the lateral parts are all deflected by the resistance of the inertia of the lead to parabolic ture. In this experiment, by measurement afterwards, I that the directly forward parts were shortened, indicating mpression, and that the backward parts were equally herefore indicating rarefaction, as might have been

The lateral parts in this experiment were crowded s could not occur in a fluid where every particle would by equal hydrodynamic pressures, but the deflections re nearly as shown in the previous theoretical diagram,

these theoretical matters, I will now endeavour to r the motive conditions just considered, may be conhe actual properties of fluid projection, particularly in e proposed areas of conic head resistance. In this restrict and define the conditional circumstances of the tly as possible, to make the matter clear, I will consider ects of unit projections first; which will occupy the whole er. I will afterwards in the next chapter, consider the continuity of fluid projection. This division will simter, as the motive effects are much more easily observed ctions; and these observations will lead us, I hope, to stimate of forces in fluids moving upon like principles motions, where some of the links of evidence disappear absorption of actual effects. To render demonstrations ssible, I will first consider the impression of unit forces small areas of extensive resistance in homogeneous g myself of the conditions proposed, 2 art. *c*, page 5.

the cone of fracture derived from a percussion will be perfect, if the area of contact is infinitely small; but as all bodies must have sensible area, actually the point of impact will be of this area, and of so much greater area as the instant deflection of the surface of the body making impact brings other parts contiguous to the area of contact into percussionary action upon the resistant mass.

c. In the case here taken, the active conditions of the homogeneous matter, assumed to surround the point of contact, are those of equal inertia and general cohesion, other forces or pressures being neglected. These conditions may be shown by the following diagram:—

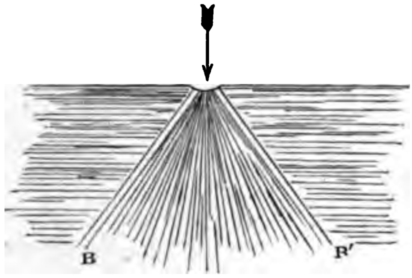


Fig. 73.—Diagram of Conic Fracture.

Let a force be impressed in the direction of the arrow shown above, in the diagram, Fig. 73, acting upon a homogeneous system of matter; then will the impressed force engender a cone of resistance in the homogeneous mass by principles discussed, 58 prop. If this impression be made in a space of time which is too small for the impressed mass to diffuse the force as a general pressure, then, we shall by the above principles, have a cone of matter separated from the general mass in the direction of radial forces within the cone, in such a plane as the cohesion of the system can be overcome. For this separation a *fracture* will be made that will circumscribe the mass of the cone, if the general surrounding homogeneous matter resists by its inertia only, and has insufficient cohesive force to hold its mass together during the impression of the percussion.

d. We may also imagine that if the cohesion of the system is great enough to resist the fracture shown in the case discussed above, or that the fluidity of the system is of so mobile a nature as to be impossible of fracture under the circumstances, that by the same principles of motion a tensile strain in the fluid system will be exerted in the *same inscribing conic plane* that the fracture would

d in a more rigid system. Therefore the line B B′ in
will be either a line of fracture if the system is rigid,
strain if the system does not permit fracture by want
It will be convenient to defer experimental demon-
his proposition until some other conditions are con-
l the conditions of a fracture are not met by it.

SITION: *That a fluid or homogeneous system of matter*
th a force sufficient to separate a conic mass of its matter,
paration by the inertia and cohesion of the entire surround-
so far as the resisting parts are in radial direction for-
ineal direction of the point impressed, at angles inclined to
of motion of less than 90°. If the impressed force Frac-
nass from the general mass, this fracture occurs where the
ression and resistance produce the greatest strain. The
t after separation forms an annular system whose in-
s conoidal.

revious proposition I have assumed the mass of homo-
tter that was impressed with the force, at the time,
ral to its influence, or as representing inertia only.
n in this matter, by the laws that Newton has so ably
l, that the force which we recognize as a motion is but

may be assumed to be supported on all sides by a conoid of the surrounding matter, which resists the instant force beyond that part which is impressed by it, and is thus rendered motive, in the same manner that we assume that the cone that received the impressed force, was supported by the resistance of the matter surrounding its axis. This may be rendered clear by the diagram below representing impressed force acting upon a homogeneous system of matter, in section through its mass. I offer at the same time definitions of the parts of the system, to make the motive principles more clear for subsequent consideration in this work.

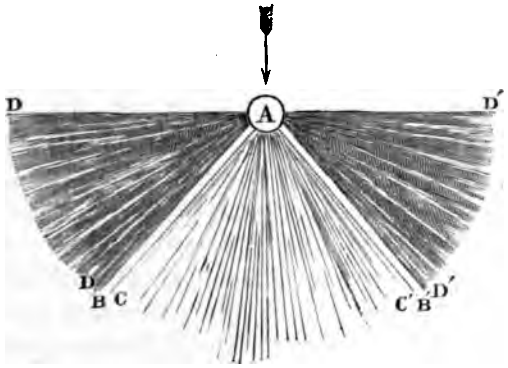


Fig. 74.—Diagram —Section of Conic Resistance and Fracture in a Homogeneous Mass.

Let A represent a body impressing a percussionary force in the direction of the arrow central to the horizontal plane D D′.

A C C′. The conic area impressed by the force upon a mass whose inertia and resistance of cohesion are overcome by it. This part (A C C′) to be hereafter termed *the cone of impression.*

A D D, A D′ D′. Sections of a ring conoid of matter surrounding the cone of impression which retains its position during the impression of the percussionary force, hereafter to be termed *the conoid of persistion.*

A B, A B′. A narrow vacuous plane, which is opened between the cone of impression and the conoid of persistion described above, if the impressed force is sufficient to fracture the system of matter. This plane of *fracture* will be hereafter termed the *plane of infraction*, or *the cone of infraction* of the homogeneous system.

b. I have felt it convenient to coin a word for this, I believe, new observation of the motive effects of impression of forces in homo-

ms of matter and fluids. I named DAD′D′D origin-
persistence; but I found, as I progressed in my work,
m became more and more inconsistent with the
ndered in experiments, so that I found it convenient
its present form, as the persistence is not *absolute* but
his conoid can only be conceived as a volume of
ater residuary persistence than other parts of the sys-
first impression of a force. I therefore, to make the
quivalent to the other parts of the system, term it a
istion, meaning thereby a conoid of imperfect per-
e continuity of the active impression.
or plane of infraction, occurs in that part of the
ogeneous system or fluid exactly where the conoid of
insufficient force of cohesion to withhold the resist-
fluid against the oblique direction of the active force
the cone of impression; therefore, the fluid or other
system of matter *breaks* in this plane, and forms the
action in the material system, as before discussed.
e above conditions to occur in all cases of a unit pro-
mogeneous matter upon an extensive mass of like
hould find that if the percussion were small, the
e or plane fractured would be very *thin;* that if the

opened by the instant impression of force upon a fluid or homogeneous system of matter. The first impact of such impression would be *percussionary;* but the body making the percussion must have mass which will carry momentum after the first impact upon the surface of impression. This mass would therefore, after the first impact, act by its momentum as a *compression.* Therefore we may imagine that the *percussion* will open out a plane, which the *momentum of compression* of the following parts of the mass will extend, assuming the force sufficient. In this manner the first impact or percussion, and the following momentum of compression would represent the motive energy of the entire projectile mass.

b. Taking another condition of compression:—Every body even in contact must, if it moves, *commence to move;* therefore, its first effort of movement will be infinitely motive to any body at rest that can resist it, so that every compression at the first instant of movement will possess force that is of the character of a percussion, so that every body impressed by a force will at the first instant receive the impression as under percussion, and every body receiving a percussion from any possible body of matter will have this followed by a compression equal to the residuary force necessary to complete the entire momentum of the projectile after its first instant of impact. This form of compression that follows a percussion, I desire now to follow in its effect on a fluid or homogeneous system.

c. Suppose a body to strike normal to a plane of matter. At the instant of contact, percussionary force would be infinite; therefore, if the intensity of the impression exceeded the molecular elasticity of the system of matter, it would strike out a cone of matter radial to its point of contact, of a certain extent and divergence in the mass. Then, as just proposed, the direct momentum of the striking body after its first instant of impact, by its following mass, would continue to press its matter forward into the impression, and the matter in front would be most *compressed* by the force; so that the continuity of the momentum, therefore, of the projectile, if in a mobile system or a fluid, would move forward in the resisting medium in equation with the resistances with diminished velocity to that of first impact, and being more resisted in front than in any other direction; *it would be compelled to take a wider angle of divergence into the lateral matter, where there would be less resistance than in the most compressed matter directly forward in the resisting mass;* or, in other words, the impulse would be deflected

is of impression, by composition with the forces of direct
into direct compression, or of resistance engendered in the
direct impression; and the cone of infraction would be
its base, or more distant parts from the point of com-
til the resistance in the lateral parts became in equili-
the impression by extension of area.

inciples of the above may be inferred from the diagram
71, page 173, where it might be shown that the first
npact might impress the forward cone only, but the con-
ne impression in a direct line by the momentum of a
deflect the surface of the cone into the lateral parts; in
rward parts, except those in direct axial line, would
er a certain projection, the lateral parts, and the con-
fraction of the cone would produce a conoid of con-
ater divergence. The constant forward momentum
ut, as it were, the conic area impressed.

experimental evidence of the last three propo-

now endeavour to select cases that may convey some
l evidence which may render the conditions discussed
three propositions more clear. For the experimental

angles of the impressed forces to diverge excessively, as might be the case with the cohesive system of some other solid bodies; as for instance of any of the metals, whose general open unequal crystalline structures would permit them to separate more easily in certain directions, or to bend under impressed forces, in a much greater degree than is possible with glass, and thereby ease off the instant effects of the direct impression of the projectile forces upon them; so that the *cone* of impression would become a *conoid.*

c. If we take a disc of stout plate-glass, of say from half an inch to an inch in thickness, and strike this with a light pointed instrument, or, what is more convenient, allow a solid ball of metal to fall upon it with moderate velocity (the circumstances of the velocity of impact may be within wide range), a conoid of the glass will be projected from the back of the disc, and this conoid will give the outline of the *plane of infraction* for *glass*, under the force impressed, as it obviously occurs in this body where the *conoid of impression* breaks off from the *conoid of persistion* that supports the surface, where the cohesion of the particles of the glass are unable to resist the strain.

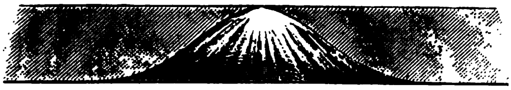


Fig. 75. Conoid projected from a Square of Glass.

d. The above illustration of the experimental effects described above was made by Mr. Collings from a conoid projected from a sheet of plate-glass three-eighths of an inch thick, by dropping a stone marble of half an inch in diameter from an altitude of seven feet upon the plate of glass. The glass was bedded with putty in a wooden frame, as a pane of glass in a window, and was placed horizontally to receive the percussion. The conoid was preserved by pasting a sheet of tissue paper under the surface of the glass before commencing the experiment.

e. In the above experiment the conoid of impression was fractured by the strain into a great many pieces; and although the outline was clear, it would have been more satisfactory to find an experiment in which the conoid could be obtained complete. This I was unable to do. It is also difficult to preserve the outline of the conoid of persistion in thick glass, which would otherwise give a much clearer demonstration of the conoidal form of fracture, as this would be more free from surface deflection than the thinner glass taken above, in which the deflection, by the elasticity of the system, produces greater extension of the base of the cone than the conditions of direct impression would otherwise permit. The best experiment that I could make with thick glass was to fire a rifle bullet close to the edge of a thick plate of glass in such a position that the axis of the cone could be free, and that no secondary fractures could occur from the excessive internal strain. In this case a splinter of glass only was obtained, but it was not split up axially, and its form was a nearly perfect section of the conoid of impression. The illustration below shows a portion of a conoid obtained in this manner drawn from the object.

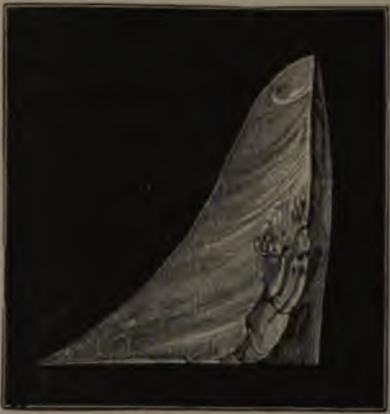


Fig. 76.—Ex. Conoidal Splinter of Glass. Drawn by Mr. Collings.

f. Many will have often observed this form of conoid of fracture, Fig. 75, clearly cut out in a London shop-window that has been struck by a stone. A similar mode of producing a conic hollow is found in mechanics, in making holes in roofing slates by a sharp instrument termed technically a *saix*. The hollow cone in the slate forms the cavity in which the head of the slating nail afterwards sinks so as to leave no projection.

g. In all cases of fracture by a unit mass of glass the *true cone of infraction*, as defined in 59 and 60 prop., only occurs from the effect of the percussion or first impact of impression at high velocity, and does not extend far into the glass. I have found that it extends generally for a distance not greater than a quarter of an inch from the point of impact; for the distance that it extends for intense forces its plane is perfectly straight from base to vertex—in fact a true cone. After this perfect cone is split out by the effect of the percussion, the deflected conoid follows for the continuity of the force of projection in the projectile by its momentum, causing a compression, as before stated (61 prop.). In these percussion cones, I have found that the angle of infraction was approximately persistent through many experiments, for the same quality and density of glass, under some considerable variations in the projectile force used. The percussion angles to the direction of impulse of the cones at the vertices, being for,—

1 inch plate-glass, ...	33°
¾ ,, ,, ...	24°
⅝ ,, ,, ...	20°

The variations under different circumstances being one or two degrees. As my researches were for qualities of motions, as before stated, not for quantities, I did not extend these experiments farther than a few experiments.

h. The following diagram will represent the theoretical separation of the effects of percussion from those of compression in the fracture plane of a plate of glass of one inch in thickness.

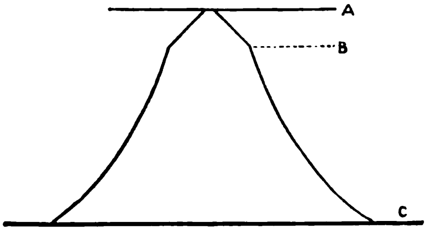


Fig. 77.—Diagram of direction of Percussionary and Compressile Forces.

A to B represents a cone of impression by percussionary force inflicted normal to the plane A on the vertex of the cone (59 prop.). B to C conoid of impression as it would be derived from compression simply (61 prop.), after the percussion plane is opened. This form will be better demonstrated by the infraction planes of free fluids further on.

i. The angle shown at B is theoretical, as is also the outline of the entire conoid of impression B to C. Actually the plane of percussion will have a directive influence for the continuity of impression, so that the one direction will generally merge into the other by compensation, which will make the plane of fracture forming the conoid of impression of a somewhat conchoidal form, particularly when the percussion that opens the infraction plane is very small. The conoid of impression, by continuity of infraction, becomes a volute, as I shall hereafter show, but the cohesion of the glass would of course resist the complete formation of such a form.

j. In any case the compression of the conoid of impression will react as a hydrostatic pressure in extending the angle at the base of the cone if this be possible through the mobility of the material system. In glass, hydrostatic pressure would be difficult to imagine, so that in this body the conditions may be considered under another form, which is only somewhat equivalent. If glass is impressed with a velocity-force sufficient to fracture it either by opening a plane of infraction by a percussion or otherwise, the fracture takes a direction in the mass in a conic plane where the cohesive force of the glass is most strained at the instant. The compression conserves the elastic force, and this conserved elasticity supports the cohesion about the axis of impression and drives the fracture outwards into the contiguous mass, where the matter is not compressed. This compels the fracture to take a more extended area, and tends to open the conoid into a bell-mouthed shape of conchoidal outline.

k. By the internal compression also in the axial line, the cone of impression in glass is split up into radial segments extending in direct planes from the axis, so that there is evidently radial strain from the compressed axis of the cone, together with circumferential tensile strain upon the cone or conoid.

63. Secondary plane of infraction for homogeneous matter. I have found that in using stout glass, a secondary plane of infraction may be formed within the compression area of the ejected cone. This occurs only when the projectile impinges against the glass in the same manner as in the previous experiment, but with greater velocity. For instance if a ball of iron one inch in diameter fall twenty feet upon a piece of glass one inch thick; in this case the ejected cone of impression produced by the impact will not be split up radially to its axis, but a secondary plane of fracture will be formed *within the conoid of impression*, which will prevent the radial lines of compressed matter reaching from the fractured circumference up to the axis of the cone. This secondary plane of fracture is caused by the elasticity of the glass being insufficiently active to bend or crowd its particles together under the impression of the direct force, or to do so with sufficient velocity forward of the point of impact to permit radial fractures to proceed up to the central line; therefore the impressed force opens out a secondary plane where the strain of central deflection is greatest upon the cone of impression. This only so far concerns us, in relation to fluid motions, as showing the strain lines in a rigid homogeneous system under percussion. But the experiment is very interesting in itself, and the phenomenon is curious. The form of the secondary plane has a very beautiful outline, appearing as in the illustration Fig. 78, as a classical vase. This form, perfect or imperfect, is produced under many nearly similar conditions, and is always of the like flowing lines. The experiment also clearly distinguishes the percussionary from the compressile plane. The illustration is taken from the original object by Mr. Collings. The dotted lines represent continuity of the plane of infraction. Further demonstrations of the last propositions applied to fluids, will be found in others forward.

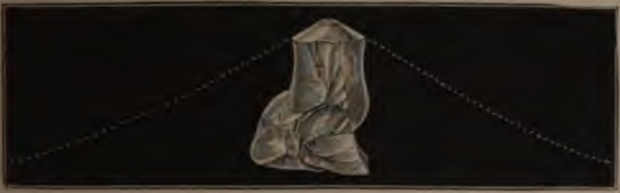


Fig. 78.—Ex.—Secondary Plane of Infraction in Glass.

Conic Resistance in Fluids.

64. PROPOSITION: *If a small unit mass of fluid matter be projected upon a large mass of static fluid with great velocity, the impact of the small mass will Fracture the static fluid in a conoidal plane, as shown by the previous experiments for homogeneous matter. The projected fluid by the continuity of the momentum of compression of its mass, on the resistance of the cone of impression, will by its momentum, intrude itself into the fracture opened by the percussion.*

a. Suppose it to be possible to make a fracture in a fluid, of exactly the same kind as that demonstrated for glass, in the previous experiments, and that this fracture were made by the velocity-force of the small mass of a body possessing fluid properties; then if the percussion had opened out a plane of infraction, the further momentum in the projectile fluid mass would suffer little resistance to oppose its entering in the open space thus formed. Further, as upon the *cone of impression* (A, C, C′, Fig. 74, page 177) great compression from the momentum of the projected mass would exist for the instant, there would be, as before shown, great resistance to oppose the continuity of the projectile motion in a direct line. Therefore we may conclude that if we had impressed the unit force with a liquid body, as the parts of this could easily separate, that the projected liquid would open out at the point of percussion and enter the space of the cone of infraction in the resisting liquid. For this condition we may further imagine that the plane of infraction need not be one absolutely opened as one of *no matter*, or vacuous space, and yet it would in all cases be the line of least resistance to the momentum of the projectile, by the tensile strain or minus resistance that the strain upon its cohesion would engender in this plane.

b. The demonstration of absolute fracture of a fluid is no doubt difficult, from the fact that in a very short space of time the surrounding pressures and conservations of elastic forces near the compressed parts, would, if any possible fracture were produced, fill up this fracture instantly, or in less time than the eye could detect movement. The demonstration of this principle of fracture is nevertheless very important in order to establish the past propositions, and for our future investigation, and it may be taken under several conditions, some of which will be followed for smaller forces in subsequent propositions, the aggregate of which, by experiments, I hope may possibly give theoretical certainty to this principle of fluid motion, as I have observed it in many more experiments than I can possibly give without great extension of the subject.

c. Taking for experimental demonstration for the conditions of this proposition, a force impressed by a small unit of liquid or homogeneous matter, with very great velocity upon the surface of a mass of liquid; we may in this case assume that if the velocity of the projectile were such that any *movements of parts of the liquid among themselves* could not occur during the time of the impression of the force, that the liquid would resist the *impression with exactly the same relative force as a solid of equal mass and of equal incompressibility to itself;* that if the momentum of the force, compressed the extensive liquid to less volume, directly in front of the impression, and we assume no time for movement of the parts exterior to the compression, a *conic fracture must occur* about the compressed parts in the extensive liquid; and the projected unit of fluid matter would enter this fracture by continuity of its momentum after the fracture in the plane of infraction, that is over the conoid of impression formed by the projection or compression within the liquid mass.

d. For experimental evidence of the above principles, the best experimental means I could devise was to take a bulk of liquid for the resisting body, and a plastic homogeneous body that would retain its impressed form for the projectile fluid body; so that the projectile should maintain the set form of the plane of infraction into which it was intruded. Considering the density, and incompressibility of water, as proved experimentally, I determined to take this for the resistant liquid; and to try *cold lead* as the plastic fluid for the projection (2 art. *e*), as I conceived lead would possess sufficient fluidity, that is, mobility of parts, and yet when the impressed force ceased to act, through resistance, sufficiently to stop its flow, it would still maintain its set form for subsequent examination.

e. For this experiment I found it necessary to construct a complete apparatus which I think sufficiently important to explain in detail. The apparatus consisted of a trough that was made about eight feet in length and of about nine inches in width and depth. A circular hole was cut in one of the ends of the trough at a little below its centre, of one and a half inches in diameter. A wooden ring three-quarters of an inch thick was turned in a lathe to the same internal diameter as the hole, and of about three and a half inches external diameter; this was made flat on both sides, six small holes were made round the ring into which wood screws were inserted, and the ring was then screwed to the inside of the trough over the hole. Removing the ring after its position was secured, a piece of parchment was stretched over the inner surface of the ring and attached to its outer edge so as to form a drum. An ordinary flat india-rubber band, such as is used for holding papers, was placed over the hole in the end of the trough inside, and the wooden ring was replaced by the screws with the drum side next the end of the trough. In this manner the parchment drum formed a small part of the end of the trough. The trough was now placed quite horizontally and nearly filled with water ready for the experiment.

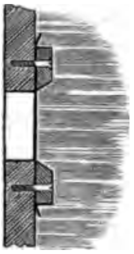


Fig. 79.—Section of Parchment Diaphragm.

f. Having procured an Enfield rifle loaded with a standard cartridge, which included ball and gunpowder in one inclosure, I had this fired at three yards' distance directly at the centre of the parchment drum in the end of the trough, and I afterwards examined the leaden ball to see how far it had followed in the plane of infraction, that I assumed the high velocity of the bullet would open out in the water; also to discover how far interfering causes might have affected my theoretical deductions; but I found the lead so clearly injected into the plane of infraction, that I feel justified in giving the whole circumstances in connection with this experiment.

g. I may premise that in the experiment the hole in the end of the trough had inadvertently been made rather too low to get quite fair resistance from the mass of water, and the trough was made of rather too thin wood, three-quarters of an inch only, so that it gave way under the side compression upon the water to the force of the bullet; from which I estimate that the resistance was rather less than would have occurred, under the conditions and dimensions given above, if the experiment had been conducted with a little more care. It nevertheless gave a very correct idea of the form of resistance, argued from my previous conception of the subject, so that I did not feel it necessary to repeat the experiment, which would have required a new trough, and waste of my time. I think, however, that the matter is important as showing a principle of resistance for liquids, such as would not be generally anticipated except upon the theories of fluid matter I have offered.

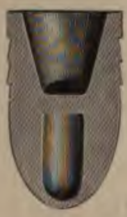


Fig. 80.—Section of Enfield Rifle Bullet.

h. For the details of this experiment. First as regards the leaden bullet, which represents our projectile fluid; a full-size section of this is shown in the engraving Fig. 80. This form happened to be extremely well adapted to exhibit the effect of fluid percussion and resistance in several particulars. Its form being nearly parabolic, it makes its percussion upon the resisting body, in this case, the parchment drum backed by the water, within a small area of contact. The point of impact being at the same time well supported by its parabolic form. It is also adapted by its section to permit the resistant *cone of impression* to be well developed in the water, as it is not so solid at the apex as to be entirely indeflectable and thereby to cause a splitting of the water in a direct line, as I afterwards discovered would be the case with a hardened steel bullet; there being an air chamber at the back of the point of the leaden bullet, that permits the possibility of some deflection, which we may take to be equivalent to certain functions of fluid mobility, within the projectile, which will be important for future consideration.

i. We may imagine that the bullet as it strikes the water is affected in the following manner:—Upon first contact the apex of the parabolic shot opens out a plane of infraction in the forward water.

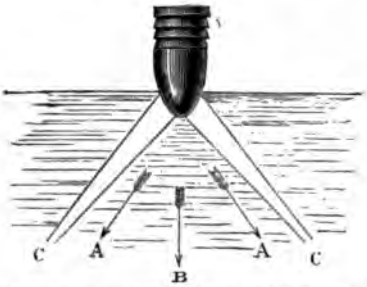


Fig. 81.—Diagram—Effect of Contact of Bullet on Water.

The form of this infraction is shown diagrammatically in the engraving above at C, C. The whole metal of the shot after this instant is embodied in a compression upon principles discussed, 61 prop., and is urged forward with its initial mass velocity. The percussion being of infinite force to the water at rest, the metal of the bullet is compelled to open out its mass and follow in the plane of infraction as that of least resistance. Therefore the lead *flows down the surface of the cone of impression in the resistant water as a simple plastic liquid would;* the point of the shot being stretched out to cover the base of the cone, as far as is possible for the cohesive qualities of the lead to do so, and the lead retains the form of the cone of infraction into which it is injected; this process being no doubt facilitated by the softening of the lead by heat engendered by the impact.

j. The lead as it is at first projected in the plane of infraction may be assumed to cover the cone of impression only to its vertex, but as the force derived from the momentum of the bullet in this projection is greater than the resistance of the cohesive force of the of which it is formed, it leaves the vertex of the cone and flows some distance towards the open infracted base. At this point periment, the lead having become very thin, it separates generally into five or six segments over the cone of impression, and in this segmental condition, its form remains fixed for future examination. In repeating this experiment, it will be found convenient to colour the point of the bullet with a little vermilion in shellac varnish, and allow it to dry, for the purpose of putting the segments together in proper order to form the complete mould of the plane of infraction after the experiment. The point of the bullet which is coloured red, of course forms the outer circumference of the conoid, as it is found at the conclusion of the experiment.

k. After the direct action of the conic resistance is complete in the water, there is a small residual force in the bullet, and a certain time for fluid accommodation has now been given to the water, so that the bullet follows a parabolic course to the bottom of the trough, and remains at from six to nine inches from the parchment drum, where the segments may be found.

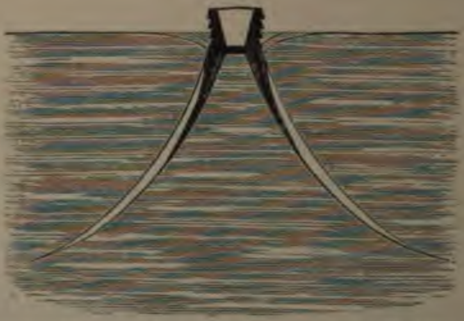


Fig. 82.—Diagram—Section of Bullet entering Surface of Water.

l. The section of the bullet as it would be at the time it is resisted by the perfect cone of impression would be as shown half size by the dark section in Fig. 82; the plane of infraction being shown open in front for its further projection.

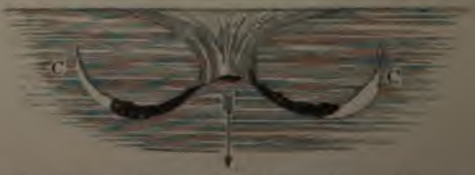


Fig. 83.—Diagram—Section of Bullet, Second Stage of Projection.

m. The momentum of the backward parts of the shot would in a mobile system suffer less resistance than the point of contact; therefore, the continuity of this momentum would further compress the conoid, so that in the next instant the projection would be as in the dark part of the engraving, Fig. 83.

n. By further continuity of the same mode of force, the outward deflection of the conoid of impression by the great momentum of the projectile after the first instant would react and attain a descending force, and the projectile would be finally set in the form represented in section, Fig. 84, above; the bullet not having sufficient elastic extensibility to continue further in the deflected plane of infraction.

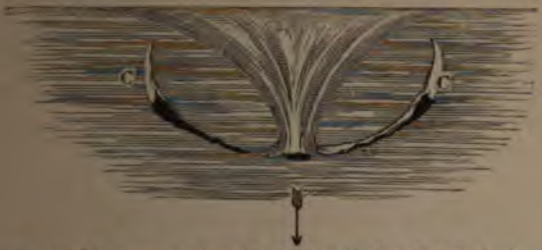


Fig. 84.—Diagram—Section of Projection of Bullet, Final Projection.

o. The exact appearance of the identical bullet here described with its segments carefully laid together in their set forms, was drawn on wood, full size from the object, by Mr. Collings the able artist, who has illustrated many of these pages, the section being as represented in Fig. 84. The central object in Fig. 85 is the diaphragm

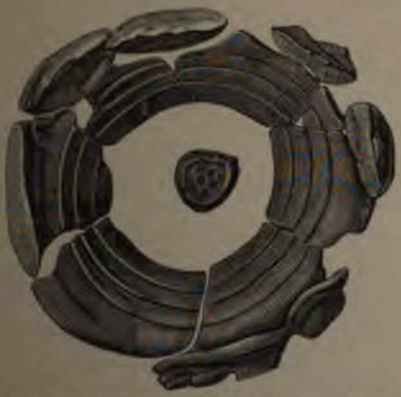


Fig. 85.—Ex.—Lead Bullet after Projection in Water, drawn from Object, Full Size.

which is more perfectly resisted, so that it does not
hange its form. The *outer edge* of the shot in the
t is, the part that previously formed the *pointed end* in
shot, has the lead rolled up to a certain extent, the
which I shall more clearly show by the motions of
ds, under somewhat equivalent conditions, further on.
nparison of resistance of water with some other bodies
t of an Enfield rifle bullet, it may be well to mention
given in our volunteers' musketry instructions which
rnished to me by a friend. The initial velocity of the
ullet used for this experiment is said to be about 1260
nd. Its extreme trajectory about 3000 yards in air. At
has force to penetrate 7 inches of elm plank, or about
dry fir timber. At 200 yards it will penetrate an iron
inch thick. It would possibly enter not more than an
r at a distance of 10 yards.
above experimental results the phenomena described
for our purposes to cease at the instant that the bullet
percussion has intruded itself into the resisting mass
a set form, that is, at the instant of complete projection,
any phenomena of reflex actions occur. Therefore at
we consider the water left with all the compressions of

65. PROPOSITION: *That in the projection of a small fluid mass at small velocity into an extensive like fluid; the impression of the small force will engender a conic plane of tension in the extensive fluid, by means of which, the projectile fluid will enter by its direct momentum; this plane of tension being to the projectile fluid the path of least resistance. The conic plane of tension produced by this means will resemble the plane of infraction produced by more active forces.*

a. If we accept the theoretical conclusions arrived at in the last four propositions, that a force impressed with any velocity upon a large mass will open out a plane of infraction into which the projected fluid will be intruded. Then in the case of smaller velocities, to which this proposition points, the impression of a small mass of fluid may be taken to be insufficient to absolutely open such a plane, except at the point of impact, as before mentioned. But in this case if the momentum of the small mass is only sufficient after this first opening to continue the projection upon the cone of impression, there will be engendered about this cone a plane of tension where a superior force would have fractured the fluid, and this plane will be that of least resistance to the direct momentum of the projectile force in the small unit of fluid projected; so that this *plane of tension* will offer the same conditions for the continuity of projection to the small force that the *plane of infraction*, shown experimentally Fig. 75, page 181, offered to a larger force in more resistant matter.

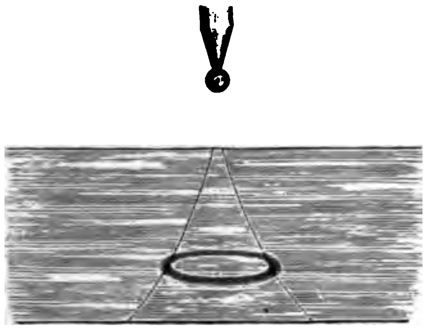


Fig. 86.—Ex.—Projection of a Drop of Coloured Water.

b. The demonstration of this proposition may be obtained by the experiment of dropping, slowly, drops of a soluble coloured liquid upon a smooth surface of water in a shallow dish or other vessel. The coloured liquid may be ink, milk, carmine, or other. A single drop may be projected from a dropping tube, or a point as that of a quill pen. When the drop falls upon the liquid surface it is observed to separate as it enters and to form a ring. The appearance being exactly as though a solid conoid of resistant matter existed under the liquid surface upon the vertex of which the drop falls. The vertex of the invisible conoid appears to pierce the drop so that henceforth it continues to glide down the surface of the cone to the bottom of the vessel. Upon further refinement we find that other conditions occur in the motion of the ring besides its direct projection, but the above gives the first appearance.

c. The explanation of these phenomena is generally given by philosophers as active upon entirely different principles to those now offered. In assuming properties of axial forces which are described as *vortex* motions. I do not object in any way to the term *vortex*, but I shall find it convenient in these pages to avoid it, in that, this term has sometimes been applied to mystical and unmechanical theoretical systems of motion, from Descartes downwards. Whereas all mechanical motions of matter are to my mind simple and direct, and in the cases in which I shall discuss these *vortex motions* they are very clearly only deflections, by resistance, after the manner of ordinary elastic reflections, following known, and with care, easily demonstrable physical laws.

66. PROPOSITION: *That the principles of motion engendered in a mass of fluid impressed by a small unit of projected fluid, will be also relatively and proportionally engendered within the smaller projected fluid unit. That the cones of impression and infraction in the two fluid bodies will be brought in opposition upon contact, and act in an inverse direction the one to the other, subject to the conditions of the relative freedom of the masses from surrounding forces.*

a. That the projectile unit in the last experiment should be subject to the same principle of action of motive forces within it, as a larger mass, might be inferred, but the conditions found in its motive parts render several particulars of the forms, that the motive parts assume different from those observed in the projection in the larger masses. The general condition of the above proposition will be best discussed upon experiment.

b. If we let a drop of water coloured with soluble colouring matter fall for six inches, as in the last experiment, upon a still surface of water contained in a vessel two or three inches deep, the drop after contact upon the surface will be partially reflected and will partially enter the liquid. The part entering will divide upon the conoid of impression incipiently formed by principles already discussed, and by this division form a ring of the coloured water, which will glide slowly down the cone of impression, being at the same time resisted by the conoid of persistion. The principles of the above may be shown most clearly by a diagram as follows.

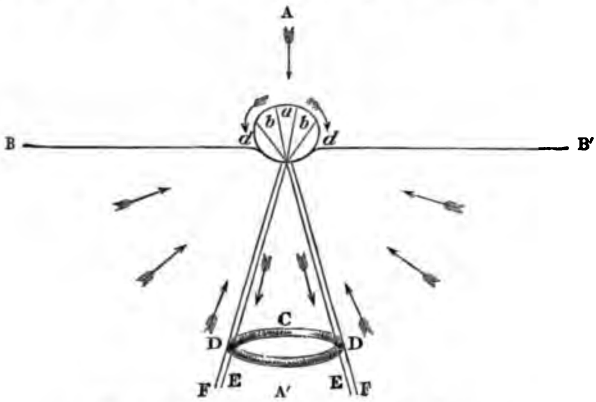


Fig. 87.—Diagram—Parts of the Whirl-ring System.

Let the following parts of Fig. 87, represent the drop system completely.

A to A′. The line of projection of the force, in this case engendered by the attraction of gravitation simply.

B B′. The liquid surface or plane of resistance to first impact.

C. A projectile ring.

D D. Conoid of persistion extending from F B and F B′ on either side to the axis A A′.

E E. Cone of impression extending to the point of impact of the drop under *a*.

F F. Cone of infraction, the plane of greatest elastic tension in which the projectile drop moves with the least resistance, shown by parallel spaces F E on both sides of the diagram.

a—Inverted cone of impression within the drop, the part which is reflected by the release of the instant compression after contact, by reaction of elasticity, at the point of impression of its own cone, with that of the vertex of the cone of impression, directly under it.

b—The part of the drop whose momentum is maintained after

in the plane of infraction in the drop. This part enters
ı the plane of least resistance (cone of infraction) as a
is shown as an after phenomenon projected down the
ession at c.

ll be seen that this part of the drop does not make percus-
e water surface direct enough to enter the cone. I antici-
is part generally adheres to the water surface, and that
he drop *bb* are emptied out, as it were, by the jerk of the
ıpon contact of the drop leaving the portion *dd*, which
eflection by central resistance, oblique momentum, so
bly passes under and towards the centre and adheres to
drop, if the drop system is not very cohesive; or it may
part is carried in with *bb*; but I will return to this
e it can be made more clear by other phenomena yet to
d. The conditions of the above principles will be some-
d by the cohesion of the drop, a larger ring being gener-
d if the colouring matter has greater viscosity, as for
h drops of milk, or of ink from the mucilage this last
Vith very weak projections also of viscous matter nearly
rop appears to be drawn into the cone of infraction.
on of the meeting of the two cones of impression
nstantly formed on contact is best observed by per-

induced to rotate upon itself consistent with the forces of acceleration on one side and the resistances it encounters on the other.

a. The projection of a unit of fluid has been shown to engender a cone of compressed fluid, in a like resisting extensive fluid by previous demonstrations. To effect this compression in the cone impressed, a certain motion in the direction of the projection of the unit is communicated to the cone, so that, as the cone of impression does not perfectly resist the compression, it becomes a *motive compression,* and the cone of impression becomes exteriorly thereby a certain active force, moving downwards from the vertex of the cone.

b. Now as the projected unit, making percussion or compression upon the conic area of resistance, is deflected from its direct course, this deflection by pressure upon the conic area of resistance accumulates its direct force upon the plane of this cone, and *accelerates* by hydrostatic pressure the deflected fluid upon it; as fully demonstrated in the conditions of deflection by resistance shown 40 prop. by experience *b* and *d.*

c. The conoid of persistion is altogether less disturbed by the impression of a unit projection than the cone of impression, which is broken off, as it were, from the active part of the system at the instant of impact, so that the conoid of persistion remains during the projection down the cone of impression in a rigid state, therefore the projected fluid of the drop or other unit enters the plane of infraction at nearly its initial velocity, and being deflected by the resistance of the cone of impression, cumulates its elastic force (by the conditions before alluded to in 40 prop.), and is accelerated upon the plane of the cone of impression, and retarded upon the more rigid conoid of persistion; so that the injected fluid, as before stated, is rotated by tangential action upon its axes of inertia normal to these planes, in proportion to the conservation of elastic forces, from the deflected projection on one side and resistance on the other.

d. Upon these principles the following diagram will represent the section of such a system which by its rotational forces takes the form of a rotating ring. The short arrows showing the direction of motive forces in the system. The exterior long arrows representing the inertia of the conoid of persistion as active but not in this case as motive. The interior long arrows representing the forces of acceleration by cumulative elasticity by deflection of resistance upon the cone of impression. The velocity of projection of the ring is at first, as the velocity of motion of rolling contact upon the conoid of persistion; but as the ring continues its projection the surface of this conoid is induced to take the same direction of motion as the ring in contact, and the surface resistance to rotation of the ring becomes less. At the same time the direction of motion induced by the ring upon the plane of the conoid of persistion causes this plane to become less static, and the rotational force of the ring to act less thereby as a projectile force by rolling contact, proportionally as it maintains its rotation upon the axis of inertia of every radial segment. So that its projection is more limited in time than its induced rotation. The rotary system of a drop is somewhat in excess of the causes here given, from the fact that the drop, before contact upon the liquid surface, is necessarily a rotary system, the conditions of which will be hereafter considered.

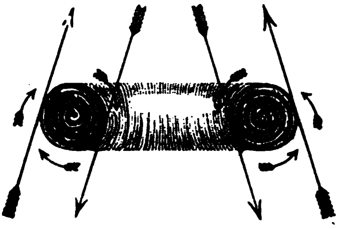


Fig. 88.—Diagram—Theoretical Section of a Whirl-ring.

e. Experiments of projecting units of coloured fluids to form rings have been discussed for a long period, the earliest I have met with are those of the projection of phosphuretted hydrogen gas both in air and in water. The most elegant methods we possess were those devised for air, by Professor Tait, and for water, by Professor O. Reynolds. These experiments I will briefly describe.

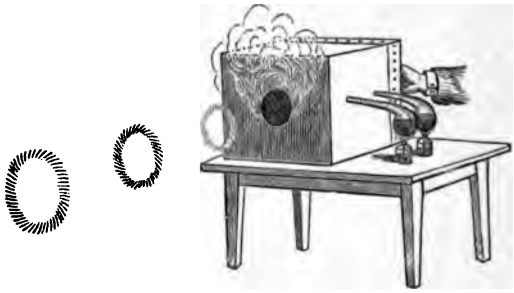


Fig. 89.—Ex.—Prof. Tait's Smoke-ring Apparatus.

f. Prof. Tait's experiment, which has priority, but the original description of which I have not been fortunate enough to discover, consists of an apparatus constructed out of an empty tea-chest without a lid, with a circular hole of three or four inches diameter cut in the centre of the bottom. The open top of the chest is covered over with a piece of canvas which is stretched as a drum-head by neatly tacking it round with tin tacks over the edges. The tea-chest is then turned down sideways. Two holes being made at a short distance apart in one of the sides of the chest and the beaks of two small retorts inserted in the holes. The retorts are supported on stands with a small Bunsen burner or spirit-lamp under each; hydrochloric acid being placed in one of the retorts, and liquid ammonia in the other. As soon as the vapours arise from these fluids and enter the chest they form a white cloud of ammonia-chloride. When the chest is charged with cloud, if the canvas drum be struck with the hand a beautiful ring will be ejected into the air, which will proceed for ten feet or more; or the canvas may be struck so softly that the ring will move very slowly for a short distance and its motion of involution may be very clearly observed. The experiment is altogether a very beautiful one.

g. In the above experiment the vertex of the cone of impression is of course *within the chest*, and near to the canvas where the direct impulse of percussion is made. The projection of a ring in this manner from a large aperture in the chest is much greater than it would be in an open fluid, from the perfect support the conoid of persistion receives by the end of the chest in which the hole is made, as discussed in principle paragraph *d* above.

h. In Professor O. Reynolds' experiment[1] a long tank about 8 feet by 2 feet by 2 feet, with glass sides, solid ends and bottom, is constructed. In one of the ends a circular hole is made about 1½ inches in diameter, in which is inserted the neck of a large tin funnel, and the joint made water-tight. A piece of sheet india-rubber is tied tightly over the outward larger end of the funnel. A small pipe leads into the funnel to conduct colouring matter to the interior. The apparatus thus prepared is filled with water, and the liquid colouring matter introduced into the funnel. If the funnel be now struck with the hand, a ring of coloured water will dart from the hole along the entire length of the trough, enlarging as it goes, with very beautiful effect.

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[1] I am indebted to Mr. J. Cottrell of the Royal Institution for this description. Prof. O. Reynolds' paper, see *Proceedings Royal Institution*, vol. viii., part iii., No. 66, page 272.

i. The above experiments bear relation to the drop experiment discussed, but the cone of impression having less resistant base, the angle of the cone deviates less from the direction of its axis.

j. In air and water every ring takes the direction of the impulse which forms it. Thus for instance, a ring may be directed in the water either to the top, bottom, or sides of the tank.

k. The expansion of the ring becomes greater as the resistance of the cone of impression is greater, relatively to the velocity of impression, as seen in the expansion of drop rings; thus it is possible to project one ring by a slight impulse slowly in air or water so that it expands and comes nearly to rest at a short distance, and then to project another ring with greater velocity, therefore less divergence, through the first one.

68. PROPOSITION: *If a liquid of unit mass be projected with a certain velocity within an extensive liquid of the same kind near the aerial surface, a ring will be formed as in the last proposition which will be deflected to the surface by the minus resistance upon its top side. Such ring for the part that protrudes above the surface will be cut off by the aerial plane and have this part of its force dissipated in surface motions. But the parts that remain in the liquid will have their forces conserved and will develop two spirals of the projectile fluid upon the surface that will demonstrate by the motive directions the internal forces present in the perfect ring system.*

a. Not having heard of Prof. O. Reynolds' experiments at the time I was experimenting myself, I made an apparatus to project liquids which gave very inferior results to those given in the last proposition *h*; but as I had not handled an apparatus of the kind described and had the engraving made (Fig. 90) of my own apparatus before I had heard of it, I therefore offer a brief description for the sake of describing other experiments that I made with it.

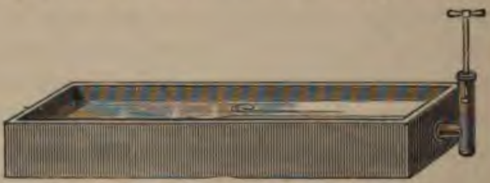
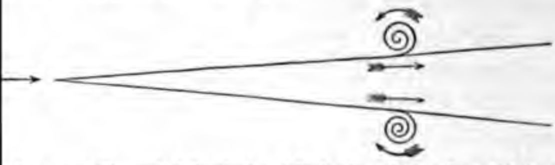


Fig. 90.—Trough for Surface Projectile Experiments.

b. Taking a trough made of inch deal, lined with zinc, such as is made cheaply by any packing-case maker for the export of goods, of the following dimensions, 9 feet in length, 18 inches in width, and 14 inches depth; into one of the ends of this trough at about the centre, I inserted a syringe which was made of a piece of ¾-inch brass pipe. The syringe was placed vertically and a pipe of the same size led horizontally into the trough; the syringe had a valve at the bottom by which it could be filled upon raising the plunger. The engraving, Fig. 90, will sufficiently illustrate the apparatus. During the filling of the syringe with coloured water a cork was temporarily placed in the hole from the inside of the trough; after the cork was removed, by pressing the plunger a ring could be projected for two or three feet. I made the apparatus at first to investigate the mode of motion for the projection of rings in water, which I hoped to be able to follow more visibly than in Prof. Tait's beautiful experiment just described, as I had previously found that experiments of the projection in gases, could generally be reproduced in liquids, and *vice versa.*

The best means that I could find experimentally to discover the principle of action of motive forces in projectile rings, was by devising means for making *sections* of such rings visible. This I effected in the following manner by the above-described apparatus. After stopping the hole in the plunging apparatus leading into the trough, with a cork, the trough was placed horizontally and partly filled with clear water to a height of about an inch to an inch and a half above the hole. The syringe described was then filled with coloured water. In the experiment, the cork being removed, and a sharp percussion made by the palm of the hand on the plunger of the syringe, a coloured ring was projected in the water. As this was projected in this experiment intentionally near the surface, the resistance to the projection of the ring being thus less on the upper side, the ring broke through the surface and its upper part was dissipated in surface motions, but the submerged portion continued by the continuity of resistances about it. At the line cut by the surface plane of the water, the internal motions of the projected liquid ring could be very fairly made out.

c. In the above experiment the ring, as it is projected, will show in its section evidence of whirling motion, in the same direction as that given in Fig. 88, page 198, as also in the axis of the ring where it is cut through in two opposite sections, at the aerial plane ırmed two small whirlpools, or deep depressions in the ıe surface is raised round these and contains the loured water, which is apparently circulating spirally centre of the whirlpools. These whirlpools remain ɔon the surface of the water for several minutes, gradually om each other by the now small effort of the conic ıat they experience. The following diagram will show ı of motion sufficiently.



–Diagram—Theoretical Continuity of Projection within a Cone of Infraction.

ition of Parts of Motions Engendered by Conic
.

ıll constantly have to recur to the phenomena now ı other experiments, it will be convenient to name the ed by any of the means described as a *whirl-ring*. I do seen to be by the last experiment directly connected enomenon of a *whirlpool*. The small *whirlpools* cut in

(58 prop.). In this case the cone of impression might not inappropriately be represented by a cone of tapering poles standing vertically upon a smooth plane. With these it is certain that any directly vertical pressure upon the vertex of the cone where all the poles are supposed to meet would only engender a compression in the central vertical pole, but that in other poles a pressure on the end would engender less compression as it would be impressed obliquely on the plane. Therefore, at a less angle to the resistance these oblique poles would be more unstable, and where the angle was much less than 90° they would have a tendency to slip outwards to an extended base. Nevertheless, a certain limited quantity of central well-supported poles would offer immediately a considerable resistance. Upon the above principles of action, in the manner proposed, it will be clear also that the axis of any conic system of resistance, fluid or other, might be replaced by an immovable solid or static body, without any change in the outward phenomena, except in the minus elasticity of a solid system.

b. It is important that the conditions given above should be made clear to our conception, inasmuch as the axis of motive resistance has been assumed heretofore to be the line of motive force in all *vortex* systems that I have read of in philosophical discussions. Upon the principles I have endeavoured to demonstrate, such a *motive centre* would be entirely fatal to the, simply mechanical, theory of unit fluid projection I offer. But this matter will be better cleared up by the experiment shown in the engraving above.

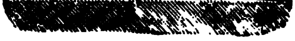


Fig 92.—Ex.—Whirl-rings projected over a Solid Object.

Take a piece of sheet lead of the size of a penny piece and cover this with white paper. Drive into the centre of the lead on the covered side a pin with a round or flat head. The paper is used only to reflect light, to be better able to observe the experiment.

ece of lead with the vertical pin upwards in the centre
sh, and fill the dish with water. Allow the water to
fectly still. If we now let fall drops of coloured
ly over the centre of the pin, upon the surface of the
drops as they fall will glide down the cone of impres-
e edge of the pin without any deflection or deformation,
he pin were not there, except that from the greater
pin offers, the cone will have a somewhat more ex-

rof. Tait's experiment (Fig. 89), we place a billiard
in the axis of the cone of impression, the ammonia-

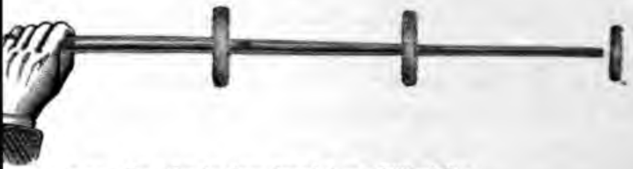


Fig. 93.—Ex.—Smoke-rings threaded on a Billiard Cue.

gs will be threaded and follow each other down the
s experiment it is necessary to project the rings quite
he direction of the cue, as the interiors of the rings
ery small angle, about 1½ to 2 degrees for the entire
, and less of course for the axis of compression, there-
quity would interfere with the desired result.
ar experiment with the cue may also be made in Prof.

they will be seen to pass uniformly down the same plane within the water. If this experiment be kept in action for a quarter of an hour, it may be observed, that throughout the whole time the cone of impression will remain quite clear transparent water, even until the *whole contents* of the vessel is tinted by the soluble dye except this cone. The spot directly *under* the cone will also remain perfectly colourless, showing that there is *no circulation* in the axial part of the system even by solution. In this experiment drop will follow drop and each arrive as a ring at the extended base of the *conoid* of impression. Every drop will remain separated from the following one and be pushed out further by it, so that after a time ten or twelve beautiful thread-like rings will expand round the base of the cone and have a very pretty appearance (Fig. 94).

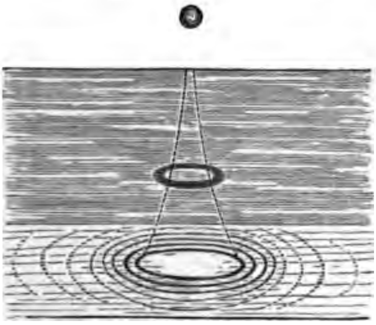


Fig. 94.—Ex.—Consecutive Drops of Aniline Solution in a shallow dish.

f. In the above experiment it is not inferred that one cone of impression remains throughout the experiment. This is of course re-formed by the projection of every drop, but the perfect freedom from motion that exists in the axis and immediately surrounding conic parts, re-forms the cone at every impression, out of the *same water as the cone was at first formed.* When the dropping ceases, the cone of impression slowly moves downwards, and falls to equilibrium with the mass, leaving a clearer spot than that in other parts of the water as before stated.

71. PROPOSITION: *The projection of a small unit or drop of liquid in a like liquid will not intrude itself into a plane of infraction unless the velocity of projection is sufficient to separate the cohesion of the projected unit or drop on the vertex of the cone of impression.*

roposition is intended to show the limits of conic
iscussed in previous propositions in slow projections.
liquid must possess a certain force of cohesion, other-
drop would not be globular (11 prop., page 30), and if
fluid resists by a cone of impression, as here assumed,
projection must overcome the cohesion of the projectile
it into a ring. If the force be not sufficient for this
et the projectile has by any means a force of continuity,
tion of gravitation, then by the continuity of impression
ing fluid the cohesion of the projectile fluid may finally
d separate into a whirl system by the force of the conic
Upon this principle we observe that there will be con-
hesion of a projectile fluid in a like fluid, and a condition
aration. This cohesion holding in two cases: 1. When
e is highly cohesive. 2. When the velocity of impression
ceed the force necessary to open out the projectile by
sion upon it. In the last case the condition will only
ry small forces, and will be only possible in the projec-
he resistance is in very fluid matter; this case I wish
w.

nditions of the above (case 2) may be observed in the
drop of writing ink placed upon the surface of still

show in the investigations of pipes and channels further on. The proposition shows that a certain impulse is always necessary to project a fluid to form a cone of infraction, which is all I wish here to demonstrate.

72. Remarks.

a. I have thought that possibly there may be for every fluid in a free space a plane of easy conic fracture under the impression of a unit force. In this plane the cone of infraction will be most readily formed. The angle which such a cone will take may depend upon the cohesive force and general physical state of the fluid in which it is formed, and will only vary according to the velocity of impression of the force in proportion to the forces necessary to restrain the free mobility of the fluid.

Assuming that fluids break under strain, the cohesion of the fluid will extend the strain, so that the conoid of impression will take an angle proportional to the cohesive force of the fluid or other homogeneous matter, as previously discussed.

b. The angle of divergence for easy fracture for free air appears to be by rough measurement of the cone of impression in the projection in Professor Tait's experiment, Fig. 89, page 198, about 1½ degrees. This angle appears to be maintained in the cone of impression under the projection of vapour rings at somewhat varying velocities. As, for instance, that of a gentle projection by a small pressure, and that of a smart blow upon the canvas drum described. The smoke-rings of course constantly enlarge upon the cone of impression, and the exterior divergence may thus vary in any degree; so that this relates to the interior angle only.

C. The angle of divergence of the cone of impression in water by the projection of a unit in free space appears to be approximately 2½ degrees in Professor O. Reynold's experiments 67 prop. *g.* When I tried it myself in the small trough shown Fig. 90, it was about 2¼ degrees, but I found the influence of the sides in supporting the conoid of persistion very material, even when the sides were distant, so that in a tank 3 feet square the cone was about 2½ degrees. A unit of coloured water projected in a tank about 7 feet square and 4 feet deep, subtended as nearly as I could measure, a somewhat greater angle, but in this case there was head resistance to the projection in the nearness of the bottom of the trough.

c. In Venturi's experiments, which I will hereafter consider, the

x volume of a fluid is through a conical tube of 3 degrees.
these and other experiments 2° 30′ of arc as approxi-
ere is considerable difficulty in measurements of this
ave not followed the matter closely or experimented
had determined from the commencement of this trea-
my investigations qualitative only, not quantitative, as
And I now only suggest that the angle of easy conic
ars to be nearly constant in some fluids at equal tem-
pressure.

ote for anyone who may be interested in this matter
ments of conic fracture should be made upon the cone
, as the surface of this cone is the only fairly invariable
ystem. The contact of an involuting whirl ring carries
ne cases, perhaps in all, part of the conoid of persistion
m, and thereby enlarges its angle of divergence as
ter shown.

es of very weak conic tension when the projectile force
l unit of fluid is nearly expended, so that the cumula-
e deflects the flowing force outwards by the entire
pression in the cone of impression, and the movement
ow that every mode of accommodation may occur in
ing fluid; then the angle of divergence of the cone

CHAPTER VI.

PRINCIPLES OF RESISTANCE TO THE PROJECTION OF FLUIDS WITHIN STATIC OR OTHERWISE RESISTING FLUIDS, CONSIDERED PARTICULARLY IN RELATION TO THE IMPRESSION OF FLOWING FORCES AGAINST HEAD RESISTANCES.

Conic areas of resistance to flowing fluids.

73. PROPOSITION: *That projectile fluids moving within like fluids will expand outwards in area of projection, until the area of resistance equals in force of elastic reaction the force-value of the area of direct impression.*

a. By *force-value* in the above proposition, I intend the same total amount of force irrespectively of the area over which it is distributed; as for instance two square feet of metal plate weighing five pounds to the foot, will have the same gravitation force-value as one square foot of plate weighing ten pounds, and these plates will balance each other if placed in a pair of scales, the force of gravitation being only distributed more, in the one case, than in the other.

b. An elastic system of fluid matter will resist movement by its inertia, and by its elasticity which acts as a repulsive force between every molecule of matter in the direct line of impression. It also resists movement in every line of convergence which can react by the cohesive forces of the system as previously considered 58 prop. *b.* Therefore forces impressed will constantly extend in area of impression, and come to equilibrium by elastic resistance at a plane where the elasticity, inertia, and cohesion of the resisting mass together equal the force of projection. In fluids we may for convenience assume these forces to extend in conic areas, as before proposed, so that the plane of resistance, becomes at a certain distance of extension of conic base, in equilibrium with the forces impressed at the vertex of a radial cone; the projectile force on is position of equilibrium will have no excess mom er projection.

ases considered 64, 65 props. in the last chapter, wh fluid enters the plane of infraction covering a c and where the plane of infraction is assumed to b *ss throughout*, that is of equal resistance per area u the cone; the resistance then increases and the velo it proportion to the extent of the *circumference* of pro ds the base of the cone and not proportionally to the se as proposed above. From this cause we may con- larly after taking some of the following propositions how it is that *unit projections* of fluids are *motive* as irl-rings, 67 prop. *f*. Whereas *constant projections* of are static upon a certain close area of conic resistance, of which, I will now endeavour to show.

of steam blow into the air from a pipe or orifice, it ar outline in the air and will not apparently mix with ghout the conic area which circumscribes its proje interior of this cone, the steam will be projecte with nearly equal force in all direct lines from th forms the vertex of the cone. To analyse the prin- projection of this *steam-cone*, we may from our luctions conceive it to be projected in the following n traced from the first instant of projection. We will his observation that a hole is suddenly opened by any essel containing steam, under a pressure greater than of the exterior air. At the first instant of the opening able to withstand the continuous friction to the projection of the jet, to constantly deflect the direct momentum of the current in the same thin plane of infraction. Therefore the cone of impression will be, as it were, quickly washed away by friction, and be replaced entirely by the radially directed projectile fluid. Nevertheless, the exterior surrounding pressures upon the conoid of persistion, not acting directly as resistances to the impulse, will remain and circumscribe the cone of projection, except for such part of this conoid as may be absorbed by rolling contact, in friction by the projection; the action of which I shall be able hereafter to give some demonstrations.

e. Upon the principles discussed above, the radial exit of the steam will form a *cone of resistance* to the forward pressures which will impress the orifice of exit from the base of this cone so as to communicate the areal external pressure as a resistance upon the internal pressure in the vessel to equilibrium according to the conditions of the proposition. The mode of exit of fluid matter into similarly elastic fluid, but at a lower pressure, may be shown by the following diagram

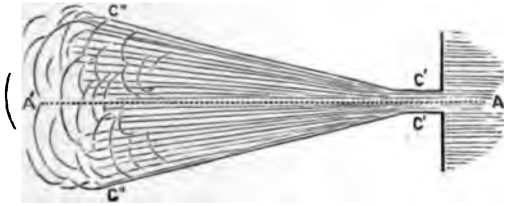


Fig. 95.—Ex.—Projection of a free jet of steam.

Let A A′ represent the axis of projection and C′ C′ C″ C″ a cone of impression somewhat enlarged by exterior friction. The interior of the cone is evidently projected forward by the constant efforts of the flowing force. Insipient cones are formed in the interior of this cone, as may be observed by the exterior rounding impressions upon the resisting air toward A′. The whole of this cone will be termed the *Cone of Resistance* in future, to distinguish it from the *Cone of Impression* defined 66 prop. *b*, page 195.

f. In the cone of impression previously discussed, the whole interior is active as a *hydrostatic pressure*, expansive in all directions. In the *cone of resistance* now proposed, the projectile force is active only radially about the axis of exit extending to its base.

g. Fig 95 represents the efflux of steam at a pressure of two

heres from an orifice of half an inch diameter in a t
It will be observed that there is a neck shown at C
to the axis, so that the cone proposed appears imperf
ngles of this neck should be shown eased off somewh
xtend C″ C′, C″ C′ to the axis A A′ the vertex of the c
in or very near the plane of the orifice, so that the reac
base of the cone is carried to the plane of efflux by c
of pressure. With cohesive fluids allowance should be m
cohesion of the jet, but in this case of steam at high press
vance need be made for cohesion, as this is so nearly overc
elastic reaction; but if the pressure in the jet only slig
d the external pressure of the surrounding atmosphere,
force of the issuing fluid would become a palpable functi
neck at C′ C′ become longer. This I will consider in t
oposition.

ROPOSITION: *A continuous flowing fluid urged by any ve*
rce will proceed slowly in a like fluid in direct lines, unless
head resistance to its forward projection expands the forwa
the flowing fluid, by elastic reaction, so that the conic resistan
rcome the cohesive forces of the projectile fluid.

e tendency of flowing fluids to preserve a uniform section *b*. The previous proposition shows by the experiment illustrated, Fig. 95, that the conic resistance acts almost instantly upon jets projected at high velocity. At low velocities we may conceive that the reaction upon the cone of resistance may be insufficient to break up the cohesion of a jet, although it is evident that in slow projections the resistant fluid must constantly impress by reaction, its force upon the forward part of the central axis of the issuing fluid; and that this force of resistance will practically extend as a cone, as previously demonstrated, radially in the quiescent fluid from the point impressed. Therefore it will support the axis of a cone formed by the radial system of resistance in the surrounding fluid, whose axis will directly impinge upon the axis of the issuing stream. In this case the cohesive system of the stream being impressed with the greatest force in its axis, will be constantly expanded by the vertex of the conic pressure of the resisting matter. So that it must, if not very cohesive, finally give way in a very limited distance by the cumulative action of constant impression; and the outward conical form of resistance will finally become actively developed, exactly in the same manner as with greater forces of projection.

c. Experimental evidence of the above conditions may be, perhaps, better demonstrated by an experiment of the celebrated Thomas Young, with the importance of which he appears to be impressed as a mode of fluid motion. I give his original description, as this is the only observation I have met with of conic resistance to fluid projection in any case.

[1] "One circumstance was observed in these experiments which is extremely difficult to explain, and which yet leads to very important consequences. It may be made sufficiently perceptible to the eye by forcing a current of smoke very gently through a fine tube. When the velocity is as small as possible the stream proceeds for many inches without observable dilation. It then diverges at a

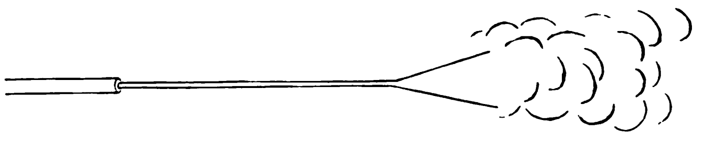


Fig. 96.—Young's Experiment of Slow Projection of Fluid.

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[1] *Light and Sound.* Dr. Thomas Young, Phil. Trans., Jan. 1800.

angle into a cone as in the last figure, and at the
ergence there is an audible and even visible vibration.
pe also affords a method of observing this phenomenon
be judged from the motion of the flame; the current
ke something like an evolution on the surface of the
s motion is too rapid to be distinctly discerned. When
is increased the vertex of the cone approaches nearer
of the tube, as in the figures below, but no degree of
ears to alter the divergency."

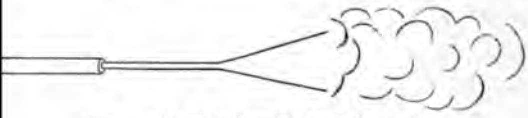

Fig. 97.—Young's Ex.—Moderate Projection.

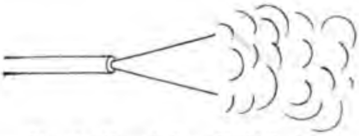

Fig. 98.—Young's Ex.—Rapid Projection.

some particulars given in the above which I cannot superior to the separating force of the conic resistance that its projection encounters. But if it be projected with very great velocity the jet separates at once into spray, or *spirts*, as it is termed.

e. In a very cohesive liquid *impelled by its gravity* in falling through a liquid of nearly equal specific gravity, the velocity may be so arranged as only slightly to exceed the constancy of resistance to the lateral parts, so that the jet may remain entirely continuous by its cohesion. This may be shown experimentally. The cohesive liquid I have tried is mastic varnish. If this be placed in a tall glass jar (18 inches high in my experiment), and a little of the same varnish that has been exposed to evaporation in the air be poured into a glass funnel above the surface of the varnish in the jar, a clear bright column of the denser varnish will slowly descend to the bottom of the jar, without separation, and will continue to flow as long as it is supplied. This column may be observed very clearly in sunshine by the small difference of refraction of the two liquids, or if desirable, the denser liquid may be coloured with a little saffron to make it more perceptible. In this projection at small velocity the column will feel the conic resistance only when near the bottom of the vessel, but even at this point, the resistance will not be sufficient to overcome the strong cohesion of the varnish. The column will therefore generally coil itself up in a conical form that will resemble a coiled rope, upon the bottom of the jar; apparently avoiding in its convolutions the axis of direct resistance to its projection near the bottom of the jar only.

75. PROPOSITION: *That the resistance to division of a current by conic resistance at any time after the first instant is equal to the force required to separate the cohesion of a mass composed of a few molecules of the fluid only at the vertex of the cone of resistance.*

a. The force capable of opening a cone of infraction for a flowing fluid has been shown to be very small by the experiments given in the last proposition; the force necessary for the continuity of the conic resistance will be found to be immeasurably so, as the following principles will demonstrate:—

Let a force as that of compression into the resistance near A, Fig. 99, open a flowing fluid directed from B to A. Let this force, acting in a direct line, through deflection by conic resistances in nearing the plane A, separate the fluid in the planes C B and C′B. Then assume that the flowing system will be at this instant of

resented in the diagram below, where the conic force is
e in separating the cohesion of the two planes C B and
crossed by the dotted line X. Now, by the continuity

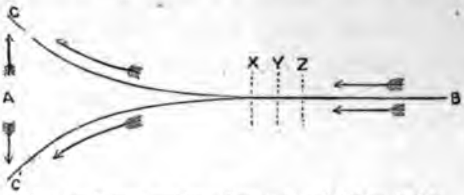

Fig. 99.—Diagram—Conic Resistance—Splitting Action.

n in the direction A to B, these planes will separate at
stant of time at the dotted line Y, and at the next
he line Z, so that at any instant of time, the separation
sive force by conic resistance will be in one *infinitely*
ly, and the force that will separate one small unit mass
s will, if constant, continue the separation of equal con-
al parts indefinitely.

continuity of projection of a jet at very small velocity
esive liquid than that taken in the last proposition, § *e*,
r conic resistance may be overcome so slowly that the
the separating action, here proposed, may be observed

in the path indicated by the dotted line as shown in the margin, Fig. 100; whereas the central jet, having accumulated gravitation impulse, will continuously open lower and lower in the liquid as the small amount of conic resistance is consecutively overcome at the descending point *c.* By continuity of the same form of motion the ring will be left far behind, united to the central column as an inverted bell, as shown in the illustration, *b c*, and the coherent jet will constantly descend until it reaches the bottom of the vessel, if this be not too deep. Many other cases could be offered, but the proposition is possibly sufficiently demonstrated. The general principles of lateral resistance to jets for continuous forces will be considered further on.

c. This proposition becomes very important as we proceed, for we find conic areas maintained by forces that are immeasurably small. The action of the cone as herein demonstrated is to split open the current at the plane of cohesion as a wedge splits a solid body, the cohesion being consecutively overcome by the splitting action of the wedge. In this manner the parts of the flowing current move directly asunder at the assumed edge of the wedge. There is therefore, in this case, no other resistance as regards the direction of the current, than the separation of the cohesion of a small mass of molecules at the vertex of the cone only, for any extent or continuity of plane, and no slipping motion to cause friction in the system.

76. PROPOSITION: *If a flowing fluid of cylindrical mass be projected longitudinally into an extensive fluid wherein there is at a certain distance a solid directly in front of the projection, so that the flowing fluid suffer greater head resistance than in a free fluid, a cone of impression will be maintained by the solid resistance, and the conoid of persistion will be disintegrated by the flowing force.*

a. The principles of this proposition have been discussed for flowing streams, 40 prop. *b*, but at that time other conditions, since offered, could not be taken which particularly concern the exterior lateral resistances (cone of persistion). In 73 prop. *c* we have a cone of persistion maintained throughout the projection in direct conical outline. This case is assumed to be possible only where the flowing projectile force is great enough to project forward the cone of impression, to form a *cone of resistance.* In the case of the present proposition the cone of impression will be supported at olid matter, and by this support the conoid of persistion 177, will be more deflected by the conserved elasticity ng force impinging against the cone of impression, so oid of persistion will become of bell-mouthed outline, as ximately shown to be in the case of projection of con- of fluid, Fig. 94, page 205. Further, by continuity of s, this conoid of persistion will be disintegrated by the f the flowing fluid upon it, and be in the same manner rd by the flowing force.

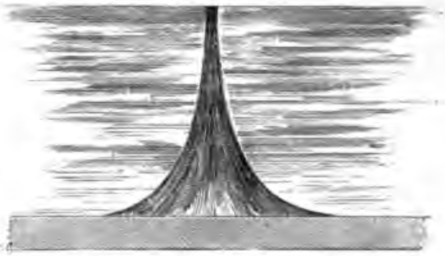

Fig. 101.—Ex.—Static Cone of Resistance to Flowing Force.

roject a stream of coloured water from a small syringe containing clear water of a few inches in depth, for an

77. PROPOSITION: *That a constantly flowing projectile fluid in a conic system of resistance, moving tangentially to the plane of the conoid of persistion, will rotate this conoid upon such centres of inertia, as may be conceived to be contained in every radial segment of matter in this conoid, if the cone of impression is rigidly supported at its base.*

a. The object of the present proposition is to endeavour to discover the mode of continuity of the flowing force beyond the supported cone of impression shown in the last proposition § *b.* For it is quite clear that if the flowing force be continuous that its backward parts will press its forward parts, so that by this means, and by the conservation of directive energy in the whole system, the active forces will tend to induce a continuous motion in the projected fluid, which will now move, as in all other cases, in the least frictional course in composition with the forces of its direct momentum and resistance.

b. The continuity of the projectile force in a jet of flowing fluid upon leaving the base of the cone, or conoid of impression, may have insufficient momentum to carry the projected fluid beyond the base, as we find conditionally in the experiment of continuous drops mentioned in 70 prop. *e*, page 205, where the force was very small, and the projection was exhausted at the time the drops reached the base of the cone of impression, where the further projection of succeeding drops constantly, upon arrival at the base, pushed the previous ones outwards, so that their movements become perpendicular to the line of original projection; in this case we may assume that we follow the cone of impression to its *final limits* as an active area of deflection.

c. Now in the present proposition the forces in the injected fluid will be assumed to be continuous beyond any base that we may conceive for a cone of impression or resistance, and on this assumption there can be no doubt that the further continuity of the motive directions of the injected fluid will act upon the same principles as are involved in the first deflections under resistance by the cone of impression. This is demonstrated, in that, by the very nature of the directive forces and the conic resistance encountered, by which the flowing fluid is constantly deflected from the cone of impression by the surface of resistance where there is the greatest accumulation of elastic force (40 prop. *b*), that this deflection will be continuous, so that at a certain point of resistance, as at the bottom of the vessel, the flowing force will be at first turned at right angles to the direc-

jection, and then by continuity of the projection it will
diverge further and further from the direction of original
ntil the fluid so urged forward must, by the continuity of
of resistance and conserved elastic force, take a circuit
pon the plane of original projection, that is, it will finally
ut the centre of inertia of every radial segment directed
xis of the projectile system, such centres circumscribing
g an annular axis to the motive system of the conoid of

In this manner, by the constancy of deflection of
in taking a constantly increasing angle, an annular
roll would be produced, the radial section of which
a complete spiral or volute. I had some difficulty at
monstrating that such a mode of motion would occur
ntry of a flowing current in a like fluid, as in my first
ts I found that in the confusion caused of injecting a
could be made out, and one is easily deceived by com-
enomena; however, in the following experiment I devised
ncrease the resistance in equal proportion, *per area* of pro-
erally upon all parts of the system, so as to produce a
ion, and thereby to permit this motive form of projection
rvable. At the same time I was able to reduce the cone
ion to a thin section so that all parts of the motive system

solution of colouring matter, for which I found common writing ink answer perfectly well. Now placing the point of the syringe just under the surface of the water vertically in the centre of the trough so as to disturb the surface as little as possible, and then steadily and forcibly injecting the contents of the syringe, the following effects were observed.

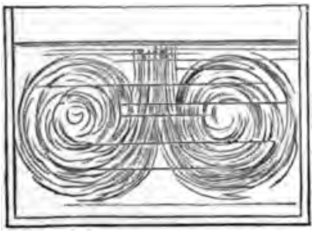

Fig. 102.—Ex.—Projection under solid head resistance.

As the colour descended it formed a conoid of extended base; but the projection continuing and being more than sufficient for this first effect, the stream lines continued to constantly diverge from their original course; they therefore curled over upon themselves until complete volutes were formed on either side outwards from the axis of the projection. As our vessel resisted by the surfaces of the glass the projectile force of the motion on two sides only; the injected liquid in order to escape this resistance was compelled to follow its course on the two free exterior sides of the projection. The volutes therefore contained the whole of the injected matter within a plane of the width of the trough, that is, half an inch in thickness, they consequently came out for observation very distinctly.

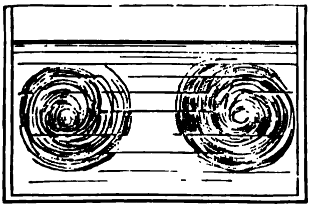

Fig. 103.—Ex.—Final Revolution of the conoid of persistion.

f. If the force of first injection of the coloured fluid was made as great as it could be conveniently by pressure of the hand on the e, the continuity of the projectile force entirely removed the ter from near the conoid of impression, and this appeare lear space at the end of the experiment. The curls inuing to revolve under favourable circumstances until th ly reached the central space as shown in the diagra t page.

lowing experiment (Fig. 104) shows the same principles hat given in the last experiment, but for air instead r, made visible by smoke, be caused to issue from a sma velocity, and the resistance be made greater by causing ween two planes of glass as in the last experiment, simil tion may be observed. The following shows the proces pieces of glass of say 6 inches square, and place the

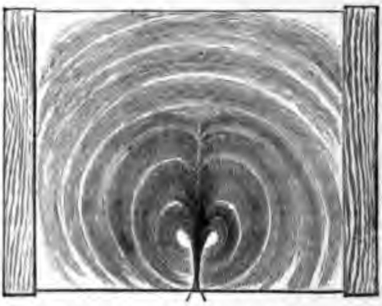

Fig. 104.—Ex.—Smoke-whirls.

h an interval of about $\frac{1}{16}$ of an inch. This may be done piece of stout card or a thin slip of wood down two ges, or upon the four corners of one of the plates, and that we have also present certain functions of vibratory motion as observed by Young (74 prop. *c*), which I will consider elsewhere in treating of the principles of sound motion. The illustration (Fig. 104) was made by Mr. Collings at my request from his own observation. It is not quite the theoretical form I should have given it in a diagram, but I have no doubt it is represented as he actually observed it, and as such it will sufficiently well support my theory.

h. The principles offered above suggest that the mode in which the impressions upon the air are made, that we recognize as sound, spread immediately in the surrounding air; so that at the back of a player upon a wind-instrument we hear nearly as clearly as in any forward or lateral direction. That this is the case we have also evidence in an experiment made by Dr. Tyndall, that the sound of a gun was proved to be equally penetrating, whether the gun was directed to the hearer or the reverse.

i. Although in the whole of the experiments given in this and the previous chapter I have endeavoured to make it clear that a projectile fluid *does* enter the plane of infraction, it may not be quite clear *why* the continuity of projection, as shown in this proposition, remains in this plane until complete volutes are involved in the conoid of persistion, as the least frictional mode of continuity of projection of the fluid. We must nevertheless assume, I think, that there is no doubt this is the case. It appears to me that the reason is clear that the continuity of projection in whirl forms is the least frictional mode of projection, in that the *projectile fluid is moulded to a forward very thin edge by its intrusion into the plane of infraction*, and that this thin edge is easily pressed forward by the backward parts of the fluid, opening out an infraction plane in front by splitting open the fluid upon principles given (75 prop.), which splitting, is deflected constantly from the greatest resistance, and thereby permits the intrusion of the projectile fluid in whirls.

j. The conditions of this proposition should not be confused with whirl-ring projections given, 66 prop., although the motive forms are similar; as in the case of a whirl-ring it is entirely projected within the plane of infraction, although it may carry with its projection a part of the conoid of persistion into its involuting system; whereas in the present proposition, for constant forces, the projection acts *tangentially* upon the conoid of persistion, so that this is *wholly absorbed* into the involuting system.

tions of parts of the whirl system of the above

ier experiments I shall have reason constantly to retur
iple of the previous two experiments, in which th
are much more demonstrable in liquids than in gases
en references, it will be now most convenient to have
the outward forms of motions engendered, clearly de-

lready named the *ring* projected by a fluid in a like fluid
and its plane section upon a surface, a *whirl-dimple,* from
of the principles of these motions being like those of
natural phenomenon, a *whirlpool.* I will further use th
, and distinguish the entire principle of motion wh
curls or volutes described, *the conic-whirl-system,*
simply. I will denote each of the curls or volut
vill call the natural form of motion caused by he
on a surface or plane just demonstrated (77 prop. *e*)
e shortest graphic expression I can find, the prefix bein
cientific language to denote duplication of similar objec
will term the directive forces derived from the cause
ich produce *whirls, whirl-force;* and will use *the evolutio*
e, as an inclusive term to denote conic resistance, infrac
on in conserved elasticity, rolling contact, and othe

the lateral whirls will constantly enlarge, and the current will project further and further into the basin, showing that the whirls reduce, by their enlargement, the resistance to direct projection. If the current has great force the centres of the whirls will form deep depressions by their centrifugal force, and the centre of the stream will be elevated, so that the current will take a restricted sectional area of projection to reduce its lateral surface of contact as much as the accommodation of the system will permit. This I have observed in many cases. In water flowing through the locks at Boulogne, in emptying the backwater of the river Liane, the central current rises about 30 inches above the lateral whirls. The following diagram will illustrate the principle.

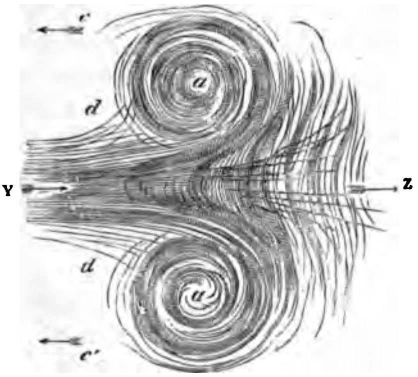

Fig. 105.—Ex.—Surface biwhirl.

b. Let the above diagram, Fig. 105, represent a part of a surface of water in an extensive basin, into which there flows a current in the direction shown by the arrows, Y to Z. In this case lateral whirls will form at a and a', and if the current be rapid, it will remove the side waters $d\,d$, and send forward wave-like deflections in front which will pass into other whirls if sufficiently free from further resistance. In this case also deflected currents will be thrown off at c and c'. By continuity of projection the entire system will become one of biwhirl rotation, and the water will flow constantly through the central area moving tangentially to the whirls. The centres of the whirls $a\,a'$ will be natural whirlpools by the tractional effects of the surrounding parts moving tangentially to them.

80. PROPOSITION: *That whirl systems are developed normal to the planes of resistance in a flowing stream, and may vary in form from a circle to a very long ellipsoid. Natural whirl forms from local resistances being most generally ellipsoidal, although the least frictional forms are circular.*

a. If we let a jet of water fall vertically into a deep vessel of water, the projection after entering for a certain depth will be deflected on all sides equally, and return towards the point of entry, as will be clearly indicated by the inward direction of the surface water towards the jet. This, from the equal lateral freedom, will produce for every radial section a circular system.

b. If we project a band of great width, as for instance that of the width of vessel into which it is projected downwards, two cylindrical whirls will be produced laterally, which will involve in a similar manner to the above normal to the surface direction of the current. If we project the same form of band horizontally below the surface of the water, a vertical *biwhirl* will be formed in which the upper and lower portions will flow in the opposite direction to the central projection. The principle of this form of projection is important, as it is in this manner that undercurrents and midcurrents are projected, which flow without excessive friction both in the atmosphere and the ocean, the instances of which I will endeavour hereafter to discuss. This form of motion produces *ellipsoidal*, or if in very extensive areas, nearly *planic systems.*

c. It is important in the above proposition to observe that the whirl system developed by a planic current will at all times tend to divide the system of the flowing fluid, so that continuous streams will decrease in volume by the amount deflected from them by the development of lateral whirls of rolling contact. It is also clear that such whirl systems would after deflection form for themselves detached systems which may never again coalesce, to form a single system—as in circular systems.

Unstable equilibrium of a biwhirl system of projectile fluid.

81. PROPOSITION: *If a biwhirl system of fluid motion, as shown in the last proposition, suffer any unequal resistance on the one side or the other; the tangential action on the most free whirl of the two will enlarge this whirl to greater area by absorption of the flowing force as it will also diminish the more resisted whirl. But if the flowing*

force would suffer greater resistance by this change, the more resisted whirl will be enlarged. Further if a motion be induced which tends to enlarge either one whirl or the other of the system, this will continue persistent, although it may be the more frictional of the two to the flowing force.

a. If we take the apparatus described 77 prop. *d*, and perforate a hole midway in each of the sides of about ⅜ of an inch internal diameter as shown in the engraving, and insert a pipe in one of these holes A leading to a reservoir placed at about a foot above its position, a current may be projected from this hole. If we add a short length of pipe to the other hole of equal diameter as shown at B; then the quantity of water the one hole supplies the other hole will let off so that we may have a current passing through the vessel from the one hole to the other.

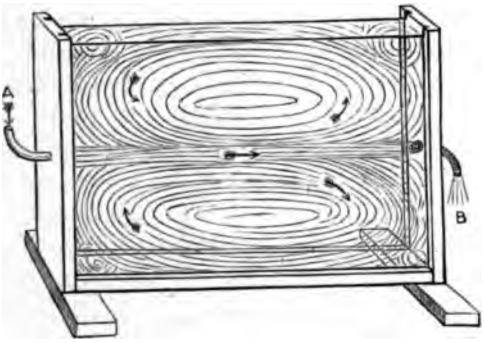

Fig. 106.—Central biwhirl projection.

b. Let the apparatus illustrated in Fig. 106 be filled with clear water and the reservoir that supplies the pipe A contain particles of matter of about equal specific gravity with the water. Then by projection of a current from A its passage through the apparatus may be clearly observed, which will be as follows:—

Upon first projection of the current, allowing a few seconds, in which motions of conic resistance will be developed, a biwhirl will be established, the whirls of which will proceed upwards and downwards, and the axis will at first take a strait direction to the opposite hole, but after a time it will be evident that this system is in unstable equilibrium, and the direction of the central current will be deflected slightly upwards or downwards. With the small apparatus described 77 prop. *d*, the directive force of the entering

pproximately maintain the axial line, and the direction
will be nearly as represented in the preceding engrav-
.

e the equilibrium of the whirl system induced more
it was clear to me that the fluid was projected in the
tus I first used, which was 15 inches only in width,
ceived was too near the opposite point of efflux for
ilibrium, or to show visible signs of unstability, the
which I desired to investigate by differences of lateral
I therefore constructed a new trough in which the
l exit were more distant, so that any inequality of
ances acted more sensitively upon the axis of projec-
new apparatus resembled that previously described,
ore, a narrow trough with glass sides, but the distance
nd exit also the depth of the trough were increased as
th of trough 46 inches, depth 21 inches, width between
inch. The inlet and outlet pipes were placed in the
ends, and were of nearly ·62 of an inch in internal

paratus, from the distance of the entrance and exit, the
rrent was made to flow through the central area with
ulty, the projected stream being evidently very sensi-

d. Now obstructing the flowing fluid so as to direct the current to flow for a short space of time upon the lower surface of the vessel, the largest whirl was formed upwards as in the engraving below, Fig. 108, as it had not sufficient force to change already induced motions by passing through the phase of a more frictional system.

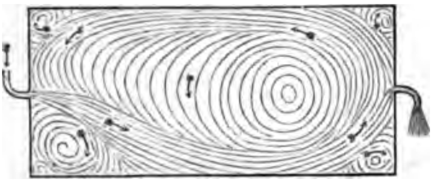

Fig. 108.—Ex.—Enlargement of Friction Whirls upwards.

e. The flowing force for the larger whirl of the biwhirl taking its circuit downwards, in this last case, although this was a *more frictional* mode of motion than the first, is very important in some operations of nature, as it shows a certain persistence of motion in some cases, as in ocean currents, when the causes by which they were produced have possibly entirely disappeared. To this I may again revert.

82. PROPOSITION: *If the area of a flowing stream be large and be projected in a fluid of like density of extensive free area, biwhirl systems will be formed; the extent of the whirls of which, if free from unequal lateral resistance, will be finally, nearly equal to that of the greatest circumference of a circle that can be described in the free area. The deflected flowing fluid moving tangentially past such areas of rotation will suffer less resistance inversely proportional to the radius of the greatest circle of motion nearly.*

a. Certain conditions of the above have been taken under principles of rolling contact 50 prop. *e*, but at the time I had not proposed any function for head resistance, so that the matter could not be cleared up, except as regards lateral resistance. This proposition shows the deflection of the direct flowing systems, formed first by conic head resistance (*biwhirl system*).

b. The above proposition will be subject to the conditions of the at § *c*, namely, that there are not present already induced motions, the quiescent area in which a current is projected, is assumed

free on all sides. If there be more or less resistance
rt of the biwhirl system, this part may be deflected
t course or circular projection, but under this deflection
a kind of elastic resistance inducing a circular motion,
use the whirls to complete their forms over other por-
free area wherever possible. This proposition is
that, it offers a theory that accounts for currents in
iescent spaces in the ocean and rivers, that are often
to the tangential movement of some distant deflected
.

position may be, for exact conditions, confined to the
large currents in free areas, as I have found that in
eas the immediate near pressures upon the whirl, that
take the place of the conoid of persistion, leave the
n small momentum and great tangential resistance, so
tem is easily deflected and deformed, although there
nt a certain amount of resistance to the deflection by
orces, which may be made evident in many experi-
or instance, in Professor Tait's projectile whirl-rings
that appear from this cause to possess a certain amount
if they meet an object, or another ring, by which they
e deflection of the rotary system. However, in any

will deflect the biwhirl formed, upwards, so that the greatest circular areas of revolution will occupy positions near the ends of the trough, that is, in positions where the greatest circle may be described. If we now take out the shaped piece of wood, turn it end for end, and replace it in the bottom of the trough as shown (Fig. 110). It will now be impossible by the position of inflow that the whirls of the biwhirl shall occupy the greatest areas of the vessel. In this case a biwhirl will be formed at the entrance, and a second further on in the most free area, so that, in this case, the three whirls united will take the greatest possible circular areas in the containing vessel. In either case the current to reach the orifice B in the one instance, or B′ in the other, will pass round a large portion of the diameter of the whirls as the least frictional course. These experiments may be varied with very curious results, but as they are only modifications of the same principles of motion, it is unnecessary to waste time in giving descriptions of these variations, except for a few important cases.

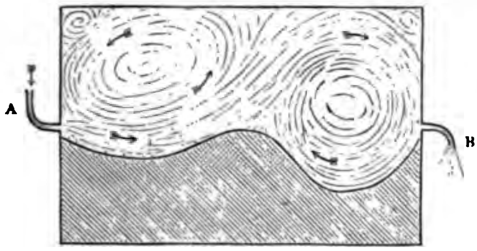

Fig. 109.—Ex.—Unequal Resistance Plane.

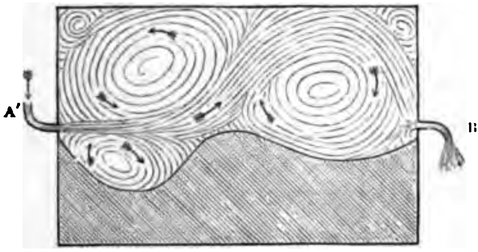

Fig. 110.—Ex.—Same as 109 reversed.

f. By the conditions of this proposition a biwhirl cannot be fully developed if the area be such as to permit one circle only to fill the

ce, unless the current crosses the central area, as any
e circular space would restrain the force of the greatest
tion, according to the conditions offered. In this case
ould if possible pass tangentially to the unit system.
n already demonstrated by principles of rolling contact,
If the vessel were of another form so that a circle could

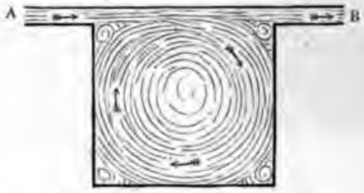

Fig. 111.—Ex.—Circular Rotational Systems.

meeting approximately equal resistances in opposite
t for instance shown in the engraving, Fig. 111, of a
the rotation would be formed in the greatest circle
inscribed in the space, but in this case there would be
paces at the corners inactive in the rotational system,
find that to complete the square, smaller rotational sys-
up in these corners. These small systems show experi-
their direction of rotation that they are *biwhirls* thrown
ee parts of the tangential system. They can be seen
the apparatus shown, Fig. 111 above, which is made six
, formed of pieces of wood a quarter of an inch in thick-

be quite clear from principles discussed that if it had to turn the angle by stream lines continuously parallel to the surface of the pipe, as generally assumed, the friction of so rigid a system as water for instance, would be immense; but by means of a whirl in the inner angle, rolling contact is insured, and the greater part of the friction entirely avoided. This may be demonstrated by the same experimental method as previously given, of cutting the angles to form the pipe out in flat sections in two pieces of thin wood and cementing these between two plates of glass to the form shown Fig. 112. The channel thus left for the water may be of square or oblong section. The water being made visible by particles is found to form a whirl in the inner angle, which keeps in constant rapid rotation which deflects the current into its course to follow the outline of the pipe. A train of smaller whirls form on each side of the exterior angle to the projectile current within the pipe. These whirls are all under restraint, and act as friction-savers, in proportion to their possible motive freedom under the circumstances, subject to the already induced motions of the water in the pipe, the conditions of which I have yet to consider.

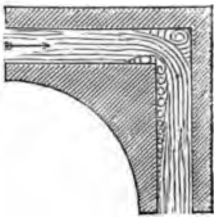
Fig. 112.—Ex.—Whirls at Angles of Pipes.

Elasticity of Whirl Systems.

83. PROPOSITION: *In a fluid system moving under the restraint of lateral resistances, rotary forces will be persistent, and they will avoid these resistances, but the rotary systems may suffer such deformations as may not be more frictional than division into separate whirl systems in frictional contact with each other.*

a. The most certain law of fluidity is that the fluid will move in the least frictional course to continue its motion. This, I hope, I have clearly shown will be necessarily so by means of rolling contact; but the system of rolling contact will be modified to the conditions present, and may not always be an evident form of motion.

b. If a fluid commence to flow over another fluid at rest, it will do so by division of the current into separate rotational systems, as shown 46 prop. *g.* If such rolling motions of contact continue, they induce a general surface motion, and this being induced in a liquid mass, this will react upon the inertia of the general tem and induce equivalent motions in distant parts.

f the supporting whirls of an overflowing system cannot
heir forms without division, for which there may be
veaker plane of resistance than that to direct projection,

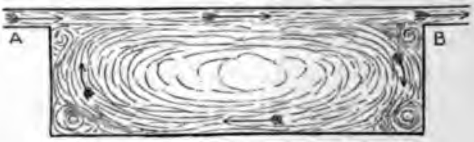

Fig. 113.—Ex.—Whirl Flattened by Restraint.

system will then continue under restraint by the tan-
es being deflected by the resistances to a greater or less
han a purely rotational system, proportionally to the
ncountered.

the diagram above, which represents the motive forms
tions are induced in a vessel similar to Fig. 53, page 141.
there would be space for two circles under the condi-
last proposition, but it is quite clear that the re-entrant
pair of whirls in such a system, coming in opposition at
g plane, would be more frictional than the restraint of
t, although deflected system, as that shown in Fig. 113
tion of the arrows.

free areas such deflections are not seen, so that these instances are purely systems under restraint.

Motions in Solid Conic Areas.

84. PROPOSITION: *If the conoid of persistion formed by the inertia of surrounding fluid be supported by near solids, or that it be formed of solid matter, such conoid will offer less resistance to a flowing force proceeding from the vertex of the conoid than any otherwise disposed system of resistant matter.*

a. In 32 prop. *n*, page 107, it was mentioned that Eytelwein, by refinements of an experiment of Venturi, constructed a cone which offered friction to the efflux of water, only by a small fraction of the whole, or ·02, greater than a perfectly frictionless outlet according to the theory I offered in the same proposition. I have shown that in such conic forms of outlet the elastic forces of the issuing fluid are released, but as elastic reactions, they impinge upon the surface of the solid cone, and the motion becomes very frictional, unless we can otherwise imagine some system of rolling contact induced; but assuming such rotation once induced, the conic form of aperture would then present conditions somewhat similar to projection down an inclined plane to the freedom of the whirl system of contact induced upon the conic surface. This whirl direction would tend to draw forward the current and increase the efflux over that of a simple or cylindrical aperture. The restrained elastic forces giving impulse to the rotational system.

b. In 77 prop. we considered the motive effects that would be brought about by supporting the cone of impression; in which we found that the flowing force was thereby deflected into the conoid of persistion, to which it imparted its momentum tangentially, until this conoid became a rotary system of motion, the effect of which was a saving of much of the friction upon the issue of the jet. In the present proposition, the conoid of persistion is assumed to be supported, and in this case, the deflected fluid is restrained in the completion of free extensive whirls, so that the friction whirls developed, are of smaller size and to a certain degree insipient, so that they rotate in many small systems upon the conoid of persistion.

c. By making the conoid of persistion a rigid system to a flowing
e produce for this, the same conditions as were observed for
y unit forces, 64, 65 props., for a free projection, wherein
formed. For in this case the conoid of persistion

rated to be fractured in the fluid system from the area of impression, so that it remained the most rigid part n. Therefore by equivalence, as argued, 73 prop. *c*, the ary system of the whirl-ring of a unit projection upon f persistion should be also equivalently represented for es, when such rigidity of exterior form is given to the as may be represented by a solid conoid of persistion. ce in this case will, however, be that as the flowing l such a conoid of persistion is constant, the equivalent ring should, therefore, be formed at every part of the ne conoid of persistion upon which the flowing force ct. From the above we may conclude, that as such pro- systems as are shown to be produced in unit projection s, by direct impulse and resistance upon the conoid of e rendered instantly rigid by the percussionary action npulse; that we may also imagine that by making the ersistion equally rigid throughout by any other means, greater impulse, as by that of a constant flowing fluid, e motions of rotation will be induced everywhere upon f this rigid conoid as in a projectile whirl; that these ns will also be so disposed, by their deflected directions, o save friction against the solid conoid, but also by the scussed, in 39 and 67 props., of conservation of energy ed system, to use the flowing force so diverted to pull current itself—exactly as we find the projected whirl- nes the resistance in front by the same principles of of energy under like deflections.

the whole pipe conical direct from the vessel of water, giving to the cone the proportions of nine times the length of the diameter at the aperture from the vessel, and making the cone in the ratio of 18 at the outward end to 10 at the aperture of the vessel, the discharge of water was more than double that of a simple pipe of the same internal diameter, that is, the water from the conic pipe flowed out in the proportion of 24 to 10 from the cylindrical pipe.

e. In this experiment the angles of entry to the pipe were eased off so as to produce an easy flow, into the form given by the internal part of the *vena contracta.*

f. Venturi rightly conceived that the air resistance was the principal cause of the acceleration, but in what manner this acted, he was not able to make out satisfactorily to science. His demonstration that it was *so*, is important, which was that if water flow out of a vessel through a hole in a thin plate under an exhausted cylinder of an air-pump, that it flows at the same rate as in the open air. But that if a conic pipe be added to the vessel in air, the outflow is increased.

g. In Venturi's experiment, important as it was as a matter of fact, he had in no way removed the difficulties that were felt by earnest philosophers at the time, in showing how the pressure of the air might be a cause of acceleration of the outflow from a conical tube, as the area of aerial resistance was clearly greater, it appeared rather that, from this cause, the outflow should have been *less.* But the greatest difficulties that were felt, were that Venturi's experiment demonstrated a fact that appeared to be contrary to all principles of frictional resistance of fluids by solids, which were conceived to be gliding motions, in that in his experiment, by *increasing* the area of surface of resistance to the flowing stream, which was evidently done by *adding* a conical pipe to the outflow, the total resistance, as measured by the increased outflow of water from the pipe, was *decreased.* Whereas the resistance ought, by principles of plus surface adhesion and friction, from the larger surface exposed to gliding motions of the liquid moving in the stream lines, which Venturi otherwise fully accepted, as his discussion of lateral communication of motion show, to have caused the resistance to be materially increased, and the outflow to be thereby proportionally less.

h. To return to our proposition. It will, I presume, be easily understood from previous demonstrations of principles of whirl motions, that with a conical pipe, that would represent, the form of

l plane of infraction of a liquid, or more correctly that
oid of persistion, that if the divergence of this conoid we
t the whirl systems induced and impelled by released ela
a previously cramped system, moving upon the plane cono
stion, made an exact half-revolution on themselves up
l plane, that perfect rolling contact would be assured, a
nentum of the flowing force and released elasticity wou
rved in the rotational system. That this is so, I will no
ur to prove by experiment.

the investigation of the motive principles of Venturi's co
ed the same construction of shaped pieces of wood cement
plates of glass, as previously described, which may
ed, as before, to isolate a longitudinal diametrical secti
rrent under greater although equally distributed late
es. For this I constructed a flat tube that at the entran
uarter of an inch square, the two opposite sides of whi
ade, by the form of the slips of wood used, to give t
cavity a convergence outwards so as to produce a chan
aight trumpet shape for the one section only; the ot

the forward resistance, and to render the motion slower, following the same principles as before discussed. For this object I reduced the space of outlet at the outward edge of the conoid towards B by making it one-eighth of an inch only in depth, retaining the quarter of inch square inlet at A, as before — the plan of the apparatus being as that shown, Fig. 115.

k. With this apparatus, having first stirred some coffee-grounds in a supply-cistern, and permitted the mixture to flow through the cone, the motions of the particles as they passed out in the current could be clearly followed, the general directions of which were as follows:—The central stream flowed outwards to constantly increasing area, following fairly a general direction intermediate between that of the axis and the outline of the sides of the cone; whereas the nearer side water was more and more deflected, until at near the borders of the current, perfect whirl-systems were developed, and the particles of coffee were seen, as shown in the engraving, whirling with great velocity, in the direction calculated to pull forward the central current.

l. The above experimental contracted cone, from the resistance of the adhesion of the water to the flat sides of the glass, must not be observed for production of an absolute acceleration of the entire stream, but for increasing local resistance to render the actual motion which occurs in a cone visible at the most free surfaces, and to show the mode in which acceleration is attained when the motive forces are more free from restraint, as in a complete cone of circular section.

m. I have before observed (72 Remarks, *c*, p. 200) that theoretically the cone of Venturi should exactly follow, or be only in slight excess of divergence from, the outline of the plane of infraction in a free fluid of equal density to the fluid projected. The angle of divergence should also bear some proportion to the velocity of the current, and possibly to the plane of easy fracture of the fluid. I have not had time to follow this matter as I at first intended, but I make out from experiments of Venturi and Eytelwein that this is at least nearly the case. In the exact form of exit given by the plane of infraction, which is largely dependent upon elastic reaction expansions, the loss of volume at exit, from a properly formed cone, should not much exceed the theoretical discharge of free projec-
at half the pressure due to the height of column, in the supply
r, as given in 32 prop. *u*, page 106.

n. The direction of the efflux from a cone being thrown by the whirl force *transversely* to the line of motion, the velocity of efflux is by this cause, as well as the reaction of elastic compression, in inverse ratio to its additional volume of efflux. This is also the case with a short pipe added to a simple aperture. This fact is important to be observed, since we do not obtain any *new force* by the addition of a cone or pipe, greater than from a hole in a thin plate; this would be impossible, but only greater volume at less velocity. The momentum of the central flowing force in this case loses the conserved elastic energy shown 32 prop. *c*, the elastic forces being directed into whirl motions that overcome the near resistances simply. Thus, if we project a jet from a thin flat plate vertically, it rises in the air to nearly the height of the reservoir by which it is supplied; but if from a cone, it simply overflows at less than half this height, as before discussed.

o. A supported conoid of persistion is equally effective in permitting a larger outflow of air to that shown for water. We should conclude this from other experiments wherein motive equivalence of air and water, or other liquids and gases, are found to hold. It is unnecessary to give the experiments I have made for my own satisfaction, to show that this is the case in this as in all other instances. The principle of making the outflow aperture of the form of a conoid of persistion is largely made use of and understood practically, although not theoretically, for the forms of horns and speaking-trumpets, wherein I find a greater angle of aperture is generally taken than I should imagine necessary for simple facility of outflow of the breath. This matter, however, is complicated in cases of air motions in cones where sounds are produced with other principles which cause the vibrations, as observed by Young in free jets, that I may at a future time discuss for the conditions of sound motions. Further, the point is not very material, for practice has possibly discovered truer angles for horns and speaking-trumpets than my theory could suggest.

85. PROPOSITION: *If the conoids of impression and of persistion formed by the projection of a flowing fluid force be both supported by near solid matter, so as to remain static or nearly so, the flowing force will then escape in the plane of infraction only, and be deflected to make rolling contact upon the supported conoid of persistion at an angle greater than 90 degrees to the direction of original projection.*

a. This proposition indicates that a flowing force will continue in a plane of infraction when this is once opened, if this plane be supported by a certain rigidity in both the conoid of persistion and the conoid of impression; and that the flowing force will be deflected towards the rigid conoid of persistion. So far, this would be evident from the previous demonstrations, as it must be so deflected to make rolling contact upon the conoid of persistion; the projection being also accelerated by elastic compression upon the conoid of impression (76 prop.). We have now therefore only to consider the amount and nature of the deflection of the current where it is set free at exit. This is important for some cases, which, by generally accepted principles of fluid projection, have proved anomalous.

b. It was observed by Clement Désormes[1] that steam at high pressure issuing from a large hole in a plate would cause a light free body that covered the hole to adhere to the plate; that the steam would issue from the edges of the plate, but the plate would not be thrown off by the internal pressure of the steam, although this was much greater than the exterior pressure of the air. The same phenomenon was observed with a pressure of air.[2] Hachette constructed a cylindrical vessel open at one end and closed at the other. By blowing through this it was found that a disc of card would adhere to the aperture against the force of the wind. This apparatus may be very well replaced by a tobacco-pipe, or one of the glass pipes used for blowing soap-bubbles, and a small disc of stiff paper. If the paper be placed over the bowl when the pipe is blown through, the disc, instead of being blown away from the bowl, as would be anticipated by principles of direct current lines, is apparently attracted to the bowl, and supported so as to flutter at the rim, leaving only just sufficient aperture for the air to escape. In this experiment the bowl supports the conoid of persistion. The stiff paper disc at the first instant supports a conoid of impression upon which the issuing fluid forms at the vertex of the cone a pressure, equal to that upon the base of the cone, as previously discussed, 73 prop. *a,* and the air escapes at the base of the cone of impression, moving by rolling contact upon the conoid of persistion, which is in this case supported by the solid pipe bowl. Therefore the projectile fluid is directed in whirls upon the surface of the conoid of

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[1] *Quarterly Journal of Science,* Jan. to June, 1827, page 472.

[2] *Quarterly Journal of Science,* July to Dec. 1827, page 193.

vhich whirls, form by their deflection, currents returni
)ath of original projection, so that these, as the rolli
tinues with the adhesive force of air to the solid conc
n, draw the stiff paper in the line of the inward dir
whirls. And although the pressure upon the conoid
is pressing the disc forward, the adhesion of the whi
)orted conoid of persistion is the superior force by t
f rolling contact given by the whirl system.

found in this, as in other cases, that the same phenome
ctly reproduced in water, as in air; and as the motio

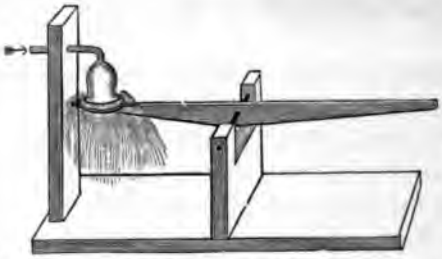

Fig. 116.—Ex.—Rigid Conoid of Persistion and of Impression.

visible, I will give the mode of production of experi-
ence of the same as follows:—

ratus is made by fixing a glass pipe, such as is used for
ap-bubbles, firmly on a stand; a disc of talc is cut of a
diameter than the outer rim of the bowl. This is
y a wooden beam, upon one end of which the disc is

quite full, Fig. 119, when by the crowding of the water by enlargement of the whirls these will finally press the disc off and let part of the water out, so as to recommence the projection of the whirls as before.

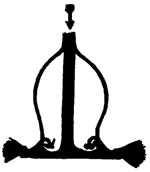
Fig. 117.—Experiment.

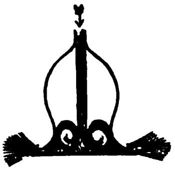
Fig. 118.—Experiment.

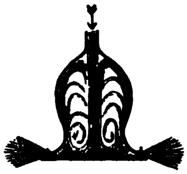
Fig. 119.—Experiment.

d. The direction of the flowing fluid after it suffers the deflection by the conoid of impression, in the experiment just given, will be thrown at first at right angles to its original projection; and as this follows the plane of resistance, that is, the surface of the loose disc, it will support this disc *by adhesion of the fluid to it* as a part of the effect, irrespectively of the after inward deflection of the same jet upon the supported conoid of persistion. This adhesion we know by experiment with water is a considerable force, as shown by tractional systems discussed prop. 34 and 35. I also anticipate that it is so also in air and gases, as I only admit *repulsive* forces, as *apparent effects*, from the impressions of the elastic surface of the flexible molecules, which form the gas (4 prop.).

86. PROPOSITION: *If a flowing force meet such a form of solid resistance as that represented in contour by a conoid of persistion, the flowing fluid taking an opposite direction to that given in* 85 *prop., that is, entering from the base and moving to the vertex of the conoid; then the greater part of the mass of flowing force will be resisted by the solid conoid, but the central or axial area of the flowing force will be accelerated.*

a. By the principles of whirl force already discussed as being active in an inclosure of a solid cone of which the motion of a liquid in Venturi's tube is an illustration, I have observed that in this case, the accumulated activity of the central area of the cone is deflected
whirl motion, in which the direct force of projection of the
ortion of the current is lost, as just shown, 84 prop. *n.*
ve reverse this mode of motion, that is, reverse the

the cone, the central force should be *accelerated*
e acting inversely, and the volume should be
ust, nevertheless, conclude that in doing this
the resistant surface is placed at an opposing
on of the current, so that it will possibly only
central axis of projection, or the part most free
nce. Under these conditions, we may assume
e central current would be fully maintained, and
ases accelerated, by the whirls increasing the
e in the full area of the flowing current, being,
sed or concentrated upon a small area of the
giving a kind of directive pull to the whirls
onoid, the flowing force in this case being used
acceleration of the central current only.

entry of a fluid at the base of a cone, the central
osed area is isolated from the side resistance by
space to form large enough whirls to reach the
ls would in this case be first engendered at the
resistance, at the mouth of the hollow cone, upon
rrent whirls had made contact, and were returning
n upon themselves, the whirls would be at first
the current forward, and then to set it free

small acceleration of the central axis of a current in all cases, irrespectively of many interfering causes.

c. The absolute motion here proposed may be shown experimentally by causing a broad stream to contract to a narrow one by reversing the inflow into the same sectional conoid as that shown at Fig. 115, page 238. The same apparent disposition of whirls, upon the surface of the cone will be observed in the motion of coffee grounds in water, as was shown in that experiment; the result being that the central current will be accelerated somewhat above the original initial velocity of the current before entering the conoid. The normal section of which in this case should be parallel as described, 84 prop. *i.* The above diagram represents this principle of motion; A to B being the direction of the flowing force. The central *projection* in this case must not be looked upon as an elastic compression which could act by any means normal to the direction of the current; as in this case the greatest normal pressure is where, by the freedom of space, the lateral whirls are most developed, that is, towards the opening of the cone. The whirling motion is quite visible by the rapid rotation of particles quite up to the open vertex of the conoid.

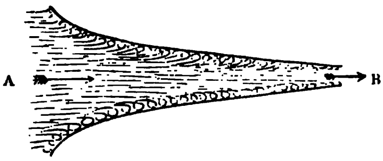

Fig. 120.—Ex.—Liquid entering a Conic Area.

d. There are some incidental circumstances which render this form of cone a vehicle for the collection of sound, which I may discuss at some future period.

CHAPTER VII.

OF CONIC RESISTANCE, TRACTIONAL FORCES, ROTA-
) INTERMITTENT ACTION IN THE PASSAGE OF FLUIDS
THE PARALLEL SPACES OF PIPES, CHANNELS, JETS,
RENTS.

ninary observations—Pipes and Channels.

ng the surfaces of resistance to cause deflections of
within a fluid flowing through a pipe or channel upon
rolling contact discussed in the fourth chapter. We
nagine that by the conditions present, if such motions
ed, that they will be excessively cramped, particularly
ipe or channel is of small diameter. Further, if we
neans imagine, that there are present in the projection
ough pipes, active elements of conic resistance, of the
is in cases of projection of fluids in more free areas,
have given demonstration in the last two chapters;
se, the whirls formed by the resistances will be also
ramped and deformed by deflections from the restric-
Further, for the possible formation of whirls in pipes,
t the influence of direct head resistance in the fluid
active cause of deflection, as it was shown to be in open
esistances in a pipe being evidently principally lateral.
onditions it would almost appear to be necessary that

a liquid moving upon the surface of resistance by which rolling contact is assured, giving freedom to the central area of a pipe, may be made out without much difficulty; but our difficulties do not by any means end here, in that, as soon as we have a continuous flowing fluid, we have then to consider tractional forces active upon it, supported by the adhesion of the liquid to the pipe or channel. Taking the whole matter which experiment has induced me to follow, I have found the demonstration of the motion of a fluid in a pipe more difficult than any other form of fluid motion I have endeavoured to investigate. Therefore, in this discussion for the elucidation of principles, I shall be compelled to offer in many cases purely theoretical ideas; finding for them only such incidental experimental demonstrations as I am able.

b. To make my ideas of the principles of fluid motion in parallel spaces as clear to conception as possible, upon the above suggestions, the conditions of fluids flowing through such spaces may be conveniently discussed under separate heads.—1. That a particle of the flowing fluid will be resisted in its forward motion by conic areas of resistance upon principles discussed, 58 prop. 2. That a particle, as a portion of a cohesive system of matter, will be withheld by the traction of following parts, and by all adhesive surfaces, 34, 35 prop. 3. That a fluid necessarily makes rolling contact on solid surface, from its infinitely mobile or jointed system, 46 prop. 4. That all accommodations occur, that are possible, in a dense material system. For the elucidation of the foregoing conditions I make the following propositions.

Forward resistance to a fluid flowing in a parallel channel.

88. PROPOSITION: *If a fluid by the presence of lateral resistances be compelled to flow in a parallel direction to planes of resistance, every portion of such planes will, by an assumed conic series of molecules directed therefrom, offer resistance to every particle of the flowing fluid for such distances as the conic series of resisting parts may be able to act.*

a. A fluid may flow *directly forward* parallel to two planes of resistances if it be equally distant from each of them. This will be clear, as any forces of resistance on one side will be in equilibrium with those on the other. Under these conditions we may assume that a certain central volume of a fluid flowing between two equally distant parallel resistances will continue in a direct line and not be influenced to flow to the one side more than to the other.

b. The conditions of static equilibrium of a particle in a fluid, given 57 prop., page 167, assure us that equilibrium would be perfectly maintained in any position of a fluid particle by assuming equal conic areas of pressure to surround the resting particle, the principles of which have been fully discussed. Further, that upon movement of any particle within a fluid, every conic area directly and laterally extending within 90 degrees to the direction of projection, would offer some resistance to forward motion as offered in 58 prop.; but that in a free open fluid the greatest *resistance* would be where the most direct momentum of the force was directed, that is, in the conic area in front of the projection. In the present case to be considered, namely, that of a parallel space, the local conditions of resistance are materially different from those considered in the last chapter, as in the long parallel spaces which form pipes, the head resistances only may be taken to be nearly the same as for open spaces; the lateral resistances from adhesion of the fluid to the walls of the pipe or channel being relatively much greater by the solid support they receive; so that altogether the head resistance may be taken to be relatively small, and such conic resistance, as can be demonstrated, will be derived almost entirely from the circumscribing lateral resistances; where such can take directive angles of less than 90 degrees to lines of direct impulse of the fluid in the pipe, to be supported by its solid walls. In this manner the resistance will be nearly as the superficial area of restraint of the containing parallel surfaces.

c. Under the above conditions in the motion of fluids in pipes and parallel spaces, we have to investigate the action of *oblique conic areas of resistance*, which do not, as in the cases previously considered in former chapters, form direct head resistances by *condensations* directly forward of the projection, but the condensation caused by the force of projection of the fluid into the resistances, may be assumed to be immediately deflected, by the obliquity of direction of possible impulse upon the lateral surfaces. In this obliquity there will be, however, such elements of head resistance, as the continuity of the solid plane of resistance will support; which will be greater in proportion to its longitudinal extent.

d. The values of the oblique forces stated above cannot be estimated in any simple components of direct head resistance such as might be assumed to occur from partial obstruction; for instance, a thin rod crossing a current would offer equal direct *head resistance* to that of a long plane of the thickness of the diameter of the rod placed longitudinally in the flowing direction of the current; but the entire resistance to the flowing fluid would be much greater in passing this long plane than in passing the rod, as the plane may be assumed to support oblique cones of resistance at every point. There is also the further condition, that the force required for the displacement of the liquid upon the plane is largely dependent upon the extent and freedom of motions of rolling contact possible to be induced in the system, and also dependent very much upon the friction of the systems of motions already induced, which offer greater resistance at the entrance of a plane, where motive forces of rotation have to be induced than in its continuity, where accommodations to this least frictional form of motion are more fully developed.

e. The geometrical principles of construction of conic side resistances which act as modified forms of head resistances, may be conceived by supposing every particle of the flowing fluid to be supported by cones of resistance extending obliquely in front of the projection to the plane of the solid walls which the fluid passes, as in the diagram below (Fig. 121), wherein the deflection of the flowing force, caused by conic resistance, is shown by the direction of the arrows in the curved line. The resistances themselves being shown by the straight divergent lines extending to the plane represented by the horizontal line at the top of the diagram. In this manner, the resistance so far as the particular cones of resistance, that are shown by radial lines and assumed to be directed to a single point A, only are active, would cause the flowing force represented by the lower arrow to be ploughed off as it were from the general central stream flowing in a parallel line with the plane of resistance, so as to take divergence from the current to the surface of resistance as shown by the direction of the upper arrow. This motive deflection ensuring rolling contact of the flowing stream upon the plane of resistance by principles discussed 43 prop. *d*, page 133.

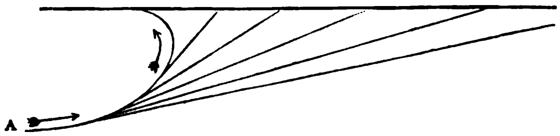

Fig. 121.—Diagram—Inflection by Forward Lateral Resistance.

f. The duplication of such a system as that proposed above, about

ing one diameter of a parallel channel, would be in every
y equivalent to the projection of a biwhirl as previously
a free area. The impulse acting in this case in a line
central axis of the channel; except that in the previous
bifurcation of the fluid about the axis, the whirls were
e derived from conic areas of direct *head resistance;*
he present case, in spaces of parallel restraint, the lateral
s may be assumed theoretically to act only equivalently
of oblique cones, so that their oblique resistances take
direct head resistances. The deflection of the flowing
n both cases in nearly the same motive form; the current
upon the same principles a tendency to flow outwards
s of projection, thus inducing motions of rolling contact
esive surfaces of the channel or pipe.

not been able to obtain by experiment the evidences I
e lateral conic resistance of a pipe, although I shall offer
nce in other propositions as I advance, but I presume
teral evidence I have previously adduced will be nearly
make it reasonable to accept the principles now offered
e necessary motions of rolling contact, which are also
principles of whirl force, already fully discussed. The
posed *varies only in degree*, according with the direction

with aniline was now projected through this divisional plane from an inlet pipe to the left of the figure, and this, by its intermediate gravity, flowed between the denser and lighter fluids. The motions of rolling contact were observed along the plane which were particularly evident at the entrance of the stream; and the angles of resistance in the planes were indicated by deflections upon the lateral resistances. There are, however, complications in this experiment that I hope to clear somewhat by future propositions.

Resistance of parallel channels by adhesion and cohesion of the flowing fluid normal to the moving parts.

89. PROPOSITION: *That the cohesive forces of a fluid moving past a parallel plane of resistance either solid or fluid, will deflect the flowing particle from its direct course in such a manner that the deflected fluid near the surface of resistance will be moved in a retrograde direction to the flowing force, but the deflected parts will be again drawn into the direct flowing stream through a cycloidal curve by traction.*

a. In this proposition I follow only the conditions of a fluid in its properties of cohesion, and of adhesion to a lateral prescribed channel throughout the distance that the fluid is assumed to move. The forward parts of any moving fluid may be assumed to resist by cohesion equally with the backward parts previously considered for traction, 34, 35 props. An equally cohesive system will move generally upon its centre of inertia by forces impressed tangentially to any part. I will now most particularly consider the functions of traction through adhesion and cohesion active upon resistances normal to the motive direction of the central particle in a current.

b. If we extend cones of resistance in the manner proposed in the last proposition shown in the diagram, Fig. 121, and take conic areas of resistance to extend forward of a moving particle by the general cohesion of the mass of which it forms a part, every portion of the fluid will then resist every other part, if it is moved against it, and every lineal or other series of particles in any direction that can be separately taken will be held together by cohesive forces extending to every point of resistance; therefore the point of resistance shown at A, Fig. 121, although not of greater resistance than any other point of the system of the fluid at equal distance from the static plane of support, may be conceived to act, as far as its force of resistance s a fulcrum of resistance to every other lineal series, or conic cules that extend in any direction *over* this point, that by the general mass cohesion of the fluid system.

ıeoretical views of fluid resistance may be partly shown ving figure in which I will take lineal resistances as ic ones for simplicity:—

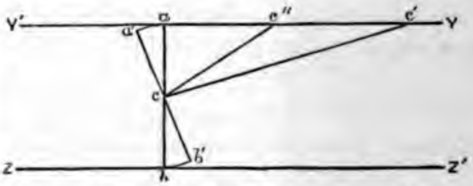

Fig. 123.—Diagram of Cohesion under Tangential Action.

epresent a static surface against which the intervening ing cohesive forces adheres and reposes, reaching with inishing force of cohesion to the lineal plane Z Z'.

' represent a moving force acting upon the intervening en its own plane and Y Y', and let the matter between Y' and Z Z' be adhesive to these planes, and cohesive s.

e a cone of resistance whose oblique base is upon the Y Y' extending to the point *c*, its vertex.

we take one transverse lineal series of molecules in the sive system of matter in the interspace Y Y' to Z Z', as ted by the line *a b*, and take our point of resistance as y, then if this rigid line be deflected by flowing force as a cohesive system moving upon its axis of inertia supported by the general resistance of the water.

f. Following the conditions of the above construction, and further assuming the termination of the lineal molecular series at a to be adhesive to the line Y Y′, then the quantity of motion represented in the figure from a to a' in the last diagram could not occur unless the rigidity of the molecular series could break asunder the adhesive force of the assumed rigid system at this point a; that is, if the adhesion were greater at a than that of the rigidity of the lineal series $a\,b$ in itself. In this case the lineal series of molecules $a\,b$ would be *bent* by the force acting from b to b' over the fulcrum c, still assumed an immovable axis of inertia.

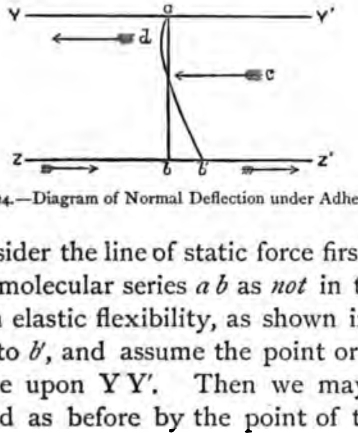

Fig. 124.—Diagram of Normal Deflection under Adhesion.

g. Now if we consider the line of static force first taken and represented by a lineal molecular series $a\,b$ as *not* in this case perfectly rigid, but of certain elastic flexibility, as shown in the figure above by the line from a to b', and assume the point or end of the lineal series at a adhesive upon Y Y′. Then we may take this lineal series to be resisted as before by the point of the arrow c, as an axis of inertia which takes the place of the cone in the previous diagram: and the movement of the flowing force from b to b' on Z Z′ acting upon this elastic lineal series $a\,b'$ would deflect the lineal series at some point between the point of the arrow c and a, in the opposite lineal direction to that of the flowing force, moving from Z to Z′, giving a *minus velocity* to a parallel of the stream as represented by the arrow d, near the static surface Y Y′.

h. In the above construction it is quite clear that no fluid could, as a free system, offer a single point of resistance or axis of inertia, as in the supposition taken for a rigid molecular series. But if we suppose the whole mass of an incompressible liquid interposed between two planes, and that the liquid is static upon, or in uniform motion upon *one of these planes*, as that of Y Y′, forming system of resistance supported by this plane, and that the moving force acting upon this system is in the plane Z to Z′ only, then every point normal to the lineal series represented by the line *a* to *b* may be considered as a point of resistance to the moving force assumed to be adhesive upon the static mobile system represented by the intervening incompressible liquid and its static adhesive plane.

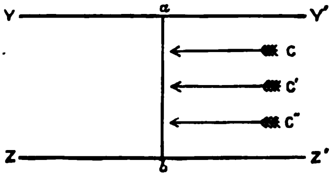

Fig. 125.—Diagram—Static Resistance.

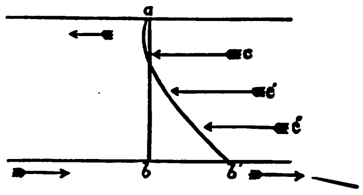

Fig. 126.—Diagram—Motive Resistance.

i. Let the points of an infinite series of resistances upon the line *a* to *b* be represented by the three arrows *c c′ c″*, Fig. 125, and assume the intervening space between the lines Y Y′ and Z Z′ to be a fluid or system possessing a certain mass cohesive flexibility; then each parallel plane of resistance will suffer a certain deflection in any vertical series of molecules by the movement of one of the parallel planes, as that of Z to Z′, for a distance parallel to itself upon the intervening space between Z Z′ and Y Y′. Let Fig. 125 above represent such a system as that described before movement, and let Fig. 126 represent the lineal deflection after a movement of the line Z Z′ to the distance *b b′*. Then will the lineal series *a b*, taking a line of flexure about the unstable fulcrum of resistance represented by the point of the arrow *c″*, deflect by its cohesive elastic force the contiguous stratum *c′* in the series to the point of the arrow *c′*. This again will deflect the lineal elastic series about the point of the arrow *c′* to the point of the arrow *c*, and this again continuing, the deflection about the point of mobile resistance *c* will complete the curve at *a*, this last being a *minus* deflection from the direction of the flowing force *b* to *b′* as it was directed in Z Z′, upon the plane assumed to be static by adhesion.

j. In the above cases, if we follow the deflected lines upon the diagrams, we may observe that we have taken the conditions of flexur only; but if we consider the same cohesion to be maintained in th deflected line, so that a point of our lineal series in moving upon t resistances carries forward the lineal series of molecules it deflec with a certain constant force derived from the flowing force, then the lateral parts will be drawn into the flowing system in the flexure lines shown in the diagram, Fig. 126, by the curved line *a* to *b'*. The above construction that I have given for matter moved in molecular lineal series perpendicular to the flowing force, with fulcra of resistance by adhesion laterally towards the head of such force, may be equally applied in principle, or extended in lineal series to any angle of direction from the central axis between the planes of resistance, or if the area be such that the solid resistance may be taken to be at infinite distance with respect to any solid parallel of the same fluid, then the inertia of the lateral fluid may be conceived theoretically to produce a static plane relatively to the impression of the flowing force, in every case, with equal results. Further, the fulcra taken to be axes of resistance supported by fluid matter forward of the projection, may with equal demonstration be taken to be fulcra of resistance, tied or supported by the general cohesion of the material system by *traction* upon matter backward of the projection. In either case the amount of the flowing force will constantly deflect any lineal projection upon lateral axes of inertia by resistances directed towards central areas of motion, and thus assure the same principles of traction lines by a general system of cohesive resistances. This connects the principles previously discussed in 35 prop., as shown *d*, page 118, with the present proposition. What experimental evidence I am able to produce for this proposition I will defer until the next.

Conditions of rolling contact of a fluid in a pipe or channel.

90. PROPOSITION: *That fluids flowing in restricted areas will be able to maintain an apparent continuous central flow under conditions of deflection and cohesion, by rolling contact upon the resistant surfaces by separating into motive units, or separate systems of motion, in which the principles shown in the two last propositions will be combined.*

a. When we compare the motive lines considered in the last two propositions, we see at once direct antagonism of motive direction of flexure in the single unit of motive fluid. That whereas at every instant the projectile forces of the central current when moving upon lateral resistance will project the force radially forward, as in other conditions of biwhirls, previously considered in 88 prop., that on the other hand the principles of cohesion of the mass sys-

d to deflect the lines of force radially backwards,
e also observe that by the principles of central pro-
vhirls deflect the fluid matter from the central axis of
wards the sides of the channels, as previously demon-
e one case; whereas by the principles of traction the
are drawn towards the central axis in the other. If
these systems again by lines about a single point of
a plane, they may be reproduced as in the following

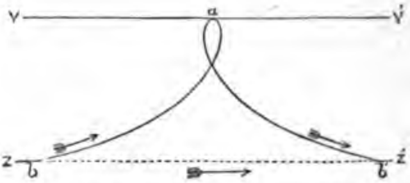

Fig. 127.—Diagram—Intermittent Action.

. 127) on the plane Y Y' represent any point of resist-
wing force, moving in the direction Z to Z'.
e line of flexure from *b* to *a* would represent the line of
of a projectile unit of fluid projected from *b* towards *b'*

shown in the diagram at *a*, Fig. 127, by the continuity of *one line of flexure* from *b* to *b'*.

c. The system of motion offered above, which relates particularly to areas of restraint, will be a *cycloidal system* derived from whirl projections re-entering the flowing system by tractional forces. There is no doubt there may be great difficulty in conceiving so intricate a system as that proposed above, but its reality appears to be most consistent with my theoretical deductions and observations of areas of restraint.

d. For the conditions under which flowing forces moving against resistant surface may be induced to divide into separate motive systems, which are necessary to support the conditions just offered, we may conceive that deflections of central forces into whirl systems will always have directive tendencies to complete their whirls, unless these motions are resisted by superior forces (82 prop.), so that by this principle, motive forces in fluids acting upon lateral surfaces where whirls are engendered by the resistance, there will always be the disposition to divide the flowing fluid, to complete separate whirls, along the plane of resistance, as closely as the mobility of the fluid system will permit. If this were not so, supposing the adhesion of the fluid to any surface to be great, it would not flow unless urged by force sufficient to entirely overcome the adhesion present.

e. Further, by cohesion, a traction will be directed from the adhesive surface of a solid to every motive part of a fluid system near to it, so that the position of the reflex motion of rolling contact of a whirl, after completion of a semi-rotation upon a surface, will be again directed towards the axis of motive traction in the area of restraint, and be free to follow the traction by the cohesive forces in a central current. Therefore a flowing fluid will be in unstable equilibrium in moving forward upon a surface of resistance, and will divide where the direction of the angle of deflection by induced whirl motions produces a greater strain upon the direct motion of the fluid in any part, than its cohesive force can withstand. The divided parts in whirl systems will upon these principles be extensive if the pressures are small, so that the whirl action is free; but may be very close where the system is cramped, to cause rapid deflection by near resistances.

f. If we can assume the action of a flowing fluid upon resistances to be intermittent, as suggested by our proposition, the difficulties of accounting for the separation of the cohesive forces of forward parts, to permit the flow, becomes almost infinitely less than could possibly be conceived for gliding planes of molecular displacement, in any possible system of cohesive matter whatever. It may further be conceived, by the principles now suggested, that by separating the units, the whirls will be thrown out more freely from the instant effects of conic resistance, exactly as the whirl-rings in Prof. Tait's experiment, described 67 prop. *e*, have projectile force, whereas constant systems are static in space, 73 prop. *e*, so that a flowing fluid may become, as regards its projection, exactly as a close series of such whirl-rings. Upon this principle, as the projectile fluid that forms the separate whirls is assumed by necessity to be compelled to return the fluid projected by deflection to the central system, so we may imagine that, by the effort of the projection, the whirls upon contact with the resistant parallel surface will make rolling contact, and that they will be instantly, as it were, thrown off by the same whirl force, after contact, back into the general flow. The momentum of this action being intermittently constant by the impulsive motivity maintained in the central space. The interior current, by this means, will ride over the whirls, making thereby rolling contact upon them, at the same time withdrawing intermittently by cohesion the fluid deflected into the lateral whirl systems.

g. In the case of a liquid flowing with great velocity by pressure through a pipe, the liquid may occupy possibly nearly the entire internal space of the pipe, and this space may be directly projectile, but it is possible even in this case, and consistent with other cases of lateral resistance, that the liquid may be surrounded by a series of small rotary systems resembling spherical drops thrown off, as whirls rolled up as it were by the continuity of the conic deflection, and as constantly unrolled by lateral cohesion, so that the same minute globular forms are maintained for the drops to act constantly as friction rollers to the flowing force. I must admit that the whole matter of this paragraph is purely theoretical, but that it is the most consistent that I can suggest to ensure the general principles of rolling contact where the current is almost entirely projected by principles which are quite evident in slower motions. Some evidence of the above may possibly be inferred in the issue of water at great velocity, or under great pressure, from a pipe, where the borders of the issuing jet are visibly broken up into spray or drops, as also by the evidence of separation in the reflection of light, which causes rapid jets to appear of a white colour.

h. I think, nevertheless, that it is extremely probable in a perfectly mobile liquid that no system of whirl motion may reach quite to a solid plane of resistance, but it is more probable that there is a certain thin layer of liquid which is powerfully adhesive and very resistant supported by the irregularities of the solid surface, so that the liquid wets this surface and renders it smooth to the friction of the rolling parts. This thin surface may possibly have a small motive direction, by impressed forces in the *opposite* direction to the current, the conditions of which I will hereafter consider.

i. For the experimental evidence of this proposition, generally, some instances of the disposition to division upon contact of flowing liquids upon surfaces of resistance may be very fairly made out. One instance of this which is very striking to observation may be found in the projection in the section of a conoid given 84 prop. *k*, where the liquid upon contact is shown to form a series of rapidly revolving whirls made visible by the relative freedom the expanding conoid offers to frictional motion.

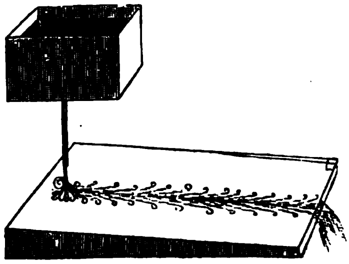

Fig. 128.—Ex.—Looped System Borders of a Current.

j. For the general experimental induction of the principle of division into separate whirl systems in parallel channels we may follow with advantage any case of the motion of liquids moving slowly through channels of small lateral resistances, for which the following experiments may be offered.

Take the apparatus described 48 prop. *h*, page 150, consisting of a can filled with water placed upon a shelf with a sloping board leading from a hole in the can to supply a fine stream of water. If we take a smooth sheet of foolscap paper and place this upon the sloping board in the manner before described, and draw the wet finger directly down the board, it will produce a moist channel of about half an inch in width. Down this channel we may project from the hole in the can a fine stream, that will continue to flow in the wet track only. Now permitting the current to flow down slowly, we may when it is steady, observe perfectly well the effect of the small amount of *side resistance* active upon it, by experiment in the manner previously proposed, of dusting the stream over with fine pepper. If we follow carefully with the eye the motion of the separate particles of pepper from the commencement of their course near the jet, we may note by these that the flowing fluid in the centre of the channel has the highest velocity, that this velocity gradually decreases towards the borders of the channel, and that the flowing fluid at its edges rests nearly quiescent, or moves in some parts with small velocity in a retrograde direction. We may further observe that every particle of the pepper is drifted by the biwhirl action of the stream more or less to the edges of the channel, from which now and then, a particle is again drawn in, but generally, at the end of the experiment, the pepper that we dusted upon the head of the stream, will be found deposited at the edges of the channel only. In fact we find that nearly every particle of pepper has followed a cycloidal curve until it has reached the more resistant edge of the channel, where it rests at the vertex of an hypercycloidal arc, or turns this vertex slightly, and reverses its direction of motion so as occasionally to return into the stream.

k. In the above experiment the projectile forces of the current are clearly evident, but it is also quite evident, that as at the end of our experiment we have not a greater volume of water at the sides of the channel, to which the pepper was directed by the moving water, than elsewhere in the stream, that there must have been throughout the entire process means for the return of the deflected water, which in this case, from the immobility of the particles of pepper, they could not in all instances follow.

l. For the separation of the system into units, if we watch the motions of the pepper for a short time, we find, that the points of greatest hypercycloidal curvature are local, and at these localities we may frequently observe the rotary motion of free whirls by the visible movement of the small particles of pepper; which shows that the rotary system of contact is divided into separate units, as we found more clearly observable at the borders of the sectional conoid shown, 84 prop. *i.*

m. We may find further experimental evidence of the same system of division, in a fine jet of water issuing into the air under pressure, by motions already induced in its system, which separate the jet into drops either directly at the orifice of issue, if it be very small, or at a short distance outward from the orifice, if it be larger. The motions of deflection, from the differences of velocity of the parts of the jet, are maintained in the air, and the liquid passes through the air upon the same principles of surface deflection as in a pipe, in which the whirls may be either incipient, as in a continuous jet, or complete, as possibly in the system of separate drops. This I shall be able further to demonstrate as I proceed.

n. In the issue of a liquid through a small hole or tube where drops only are formed, the drops most probably retain the induced rotary motions somewhat in the following manner:—

Let A′ represent the exit at the pipe or hole; a biwhirl being complete only at exit. The action of surface resistance constantly tends to produce the globular form; this being at the first instant of projection as represented at B, then at C, the complete sphere.

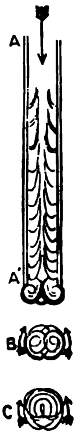

Fig. 129.
Diagram.

o. If a small pipe has any lateral restriction at or near the orifice, the whirls have greater freedom in the direction of the greatest diameter, and they divide afterwards at the exit or *spirt.* But if the channel be smooth and cylindrical the cohesive force of the liquid will draw the parts together into globular masses to form drops, which still retain in themselves the rotary motion induced by lateral resistances acting upon them, as appears by evidence of dropping experiments, where whirl-rings are immediately projected at the surface, if the drop fall from a pipe or through the air (86 prop. *a*); whereas, these whirl-rings do not appear to be immediately formed from drops projected from positions in contact upon the surface (71 prop. *b*), so that the induced rotary system in the drop is auxiliary to the motive forces that we witness in whirl-rings engendered by small effects of conic resistance (65 prop. *a*).

p. The following experiment may be considered demonstrative of the rotary or looped hypercycloidal motion of contact of small unit systems, that continue in rolling contact, separately down the stream. If we take the slowly projected column of varnish in like varnish but of less specific gravity described in 75 prop. *c*, we may note this clear stream flowing to the bottom of the jar in the sunshine by the difference of refraction. If we carefully observe the column near its surface we may notice many small globules of air and particles of matter descending with the stream. These, as they approach the borders of the column, will be found to be set into rapid rotation. This will be particularly visible with any particles of air which, by the projection, take an ovoid form and glitter, as the differences of inclination of their surfaces reflect light to the eye. In this experiment the air globules appear to move from loop to loop in a cycloidal path, as they are carried forward by the current. If the fluid system of the globule of air were such that it permitted continuity of the induced liquid motions, as we clearly see is not the case, the air globule would then be drawn out into threads to form a part of the contact whirl, and would revolve constantly near one locality in the column; but as the air bubble is held by surface forces, 11 prop., to one form, it is urged forward from loop to loop. I was anxious to obtain the same form of evidence from observing the effect of water flowing down a glass pipe by its visible action upon solid particles of matter, but I found that if the particle were large it appeared to resist motion, but if very small its motion was imperceptible, so that in very slow motions where cycloidal action could be assumed to occur close to the tube, by easy accommodation, the small resistance to the gravity of the solid particles permitted them to descend in fairly direct paths. With greater velocities, however, there was evidently present, cycloidal motion, which could be best seen by many particles descending at the same time in water through a glass pipe, by placing a pinch of sawdust in the water, but the motion being very rapid it was not easily followed to attain knowledge of the definite paths of the particles. In this case the particles of sawdust appeared to be plaiting, and crossing in every conceivable direction, as shown Fig. 130 B. It therefore appeared evident that the motions of a particle of water could only really be observed in moderately slow motions in a pipe, by the motions of another fluid moving within the water. This was not difficult to arrange. therefore fixed a glass tube of five-eighths of an inch bore, an

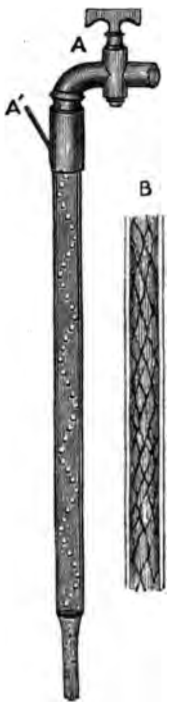

Fig. 130.
Experiments.

three feet long, to a tap from a supply cistern as shown Fig. 130 A. Now admitting air with the water into the inflow current by a small pipe A′, the particles of air were drifted in the glass pipe through cycloidal paths in constant revolution, as was clearly indicated by their glittering in the sunlight. In this case there was no doubt a certain restraint from the inequalities of density between the fluids, air and water, but the result was all I might have reasonably expected as an inference of the direction of motion in the water in so rough an experiment. In the motions of free particles and of the water itself in flowing through a pipe, there is a tendency always to produce continuity of like motion in separate parts; by these parts taking one helical direction. This is shown in Fig. 130 in the pipes A and B; but experiments in square and flat pipes show that this helical direction is a motion of composition only.

q. For another experiment to endeavour to follow more exactly the conditions of lateral resistance. I took a tall glass jar 18 inches high filled with clear water. I then drew out a piece of glass tube to a fine point and broke off the extreme end. This tube then formed a funnel with a fine stem of about $\frac{1}{200}$ of an inch bore. By supporting this funnel in a hole made through a piece of card, and placing it above the jar filled with water, so that the point entered the water, the funnel, when filled with coloured water, projected a fine stream vertically down the larger column of water in the jar, the resistance of which to the jet was easily observed by motions induced in it.

r. With the above described apparatus in projecting a dilute solution of an aniline dye, that termed *Tropoeleum* I used, but anticipate any other would answer as well. I found that as this solution issued from the point of the funnel described, it enlarged from four to five diameters. This enlargement is evidently in unstable equilibrium, for if there should happen to be any vibration in the air the column divides transversely and appears as a series of discs, one placed above the other, which resemble somewhat the annular markings of a common earth-worm, as shown in the figure by the side, which is magnified four diameters. This effect I have especially observed when a railway train was passing at about 100 yards from the position where I was trying the experiment.

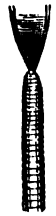

Fig. 131. Ex.

s. Quite irrespectively of the separate markings, the experiment shows the directions of internal central forces to be outward movements, so that they enlarge the stream, from which we may infer the formation of whirls that would of themselves naturally cause a tendency to division in separate units in the liquid column; these divisions being only made more visibly evident under the influence of the vibrational disturbance. If in the projection of the same column the air be quite still, the equilibrium will be disturbed in a less degree; in this case the fine stream as it descends will be marked in occasional places with local swellings. These swellings descend with regular velocity until they reach a certain point, and then separate from the column, at first apparently by being drawn together into drops, but afterwards they immediately develop their true character of whirl-rings, showing that the motive system of the column moves upon whirl principles, that in a quiescent flow, are only observable, when there is sufficient accumulated local activity and freedom in the projection, to render the motive direction of the forces present visible.

t. In the above theoretical treatment of the descending column offered, if we imagine that the original motion of the jet is at all times actually intermittent as it appears to be under vibration, it would then be clear that this intermittent action might be observed in a coloured jet, or not, under two conditions:—It could be observed if the whirls or looped systems were separated *sufficiently* to give distinct rings of colour by intermittent densities, as they evidently do under the conditions of vibration; but it could not be observed if the whirls came out of an axis *one within the other* regularly, so that their general interference of projection when the jet was viewed as a transparent object would produce simply a uniform tint. We may also imagine that if the whole column were in unstable equilibrium, a small excess of interference from any cause in any part of the column would cause the following parts to assume such conditions that they would develop their whirl forces as free systems, that is, as systems free from the cohesive restraint of the constantly flowing column of a gravitating system. It is, however, most probable that from the evidence we obtain of the motions present in very small systems, we may be best able to observe principles that universally prevail; and this evidence I think may be largely found in the projection of the small jet, under the conditions just offered, by watching attentively consecutive swellings or drops as they pass down the column.

u. It has already been shown that the dimensions of free whirls vary as their powers to overcome lateral resistances, so that after the motive forces of the projectile column have by motions induced by the resistances gained greater whirl force, the whirls spread out in the liquid by the action of tangential forces. In this case, as their projectile lines become deflected more nearly normal they must possess also less force in the direction of original projection. Therefore the next drop *following*, or the next less deflected whirl, will continue its motion with higher velocity, and overtake the first more deflected whirl. Further, when a following whirl arrives at the point of motive deflection of the former whirl, the induced direction of motion in the former will tend to draw the following whirl into the front of the previous one. This I find by observation is very evident. Further, as the lines of force in the two whirls in question come together each possessing a like form of projection, a following whirl, after it enters the system of a previous one, will continue its projection, by its less resisted direct momentum, and pass quite through the first whirl, for a certain distance, or until the direction of its force lines, that are already induced by the previous whirl, absorbs the following one into the previous system. In this manner two or more whirls will be united. The general appearance of such systems is shown in the engraving by the side, Fig. 132.

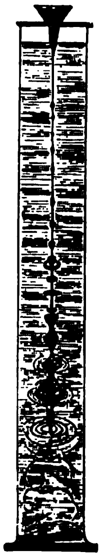
Fig. 132.—Ex. Columnar Projection.

v. It will be further seen, that by the continuity of induced deflection, of the first whirl, where the following whirl enters its system, some parts of this first whirl will be left too far behind, in the general system of combined whirl deflection, to be at once absorbed. In this case, by continuity of induced rotation, the following parts will be drawn into the general system and appear to pass inwards through the second whirl, as the second whirl in its projection passed through the first, showing thereby the perfect unity of the combined whirls in the hypercycloidal or loop system.

w. By the above reasoning I conclude that however small the division of a system of a fluid in rolling contact may be, that by the conditions of area of restriction, it may be real, and capable of development at any instant, into a larger system; by the presence of greater freedom in the plane of resistance.

x. The adjoining diagram (Fig. 133) will show by observation the method of combination of whirl and looped systems in areas free from great restraint, experimentally, in projecting a fine jet with the apparatus described Fig 132.

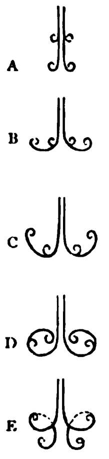

Fig. 133.—
Ex.—Section.

A. represents two whirls in a descending column in a liquid, the second advancing on the first, the flowing force of the first being deflected more nearly normal to gravitation impulse.

B. The second whirl commencing to be absorbed into the projectile system of the first.

C. The first whirl commencing to overflow and again enter the second.

D. Continuity of the same form of projection.

E. The projection of the first system through the second completing an hypercycloidal or *looped system*.

y. That the principles of division by lateral resistance into separate systems occur generally also in gases, may possibly be best inferred, by the projection of hydrogen through a small pipe, in which case, if it be lighted, an intermittent flame will be produced, particularly if the gas be carried away from the aperture by a current of air, at a greater velocity than it can diffuse itself in space. This property of intermittent action, forming thereby intermittent units of projection in hydrogen, is made evident in the well known experiment of singing tubes, the intermittent explosions of which are possibly the simplest and most direct modes of producing musical sounds. The same forms of intermittent action are also apparent in the whirl systems induced in all musical pipes, as I will endeavour at a future time to show. The same principles of division may be observed in the projection of one current of air over another, where the line of contact becomes visible, as cloud, through difference of temperature, the condensation of vapour producing series of equal small whirls, that we term a mackerel sky, as before mentioned.

z. The principle of division is very observable in air in the experiment of projection of smoke between two planes of glass, shown Fig. 104, page 222, which I left entirely to Mr. Collings to delineate, by the phenomenon he witnessed, following the means I gave. In this experiment the lateral freedom is much greater than in a pipe, so that the whirls complete a greater circuit, and do not form loops. The nearest approach to sufficiently static resistance being in this experiment near the entrance of the jet, as shown in the figure, before the whirl force is greatly diffused over extensive radial areas. The same experiment may also be used to demonstrate the vibration in jets, that Young so acutely observes in the experiment given 74 prop. *c*, page 213.

a. If we accept the general principles of this proposition with such demonstration as I have been able to give in this very difficult matter; the projection of a current in a pipe or jet will resemble very closely the continuous separate projection of whirl-rings, which are assumed to be by this theory packed as closely together as the system of accommodation of the fluid will permit, these being alternately collected by reflex action, that converts these whirls into loops, which permit the deflected fluid to re-enter the central system by traction. If we accept this as a general principle, we may still admit the influence of the special surface resistances of the pipe, which will have necessarily a force-value higher than the resistance of a free fluid to the friction of projectile whirls; and these resistances by their nearness will modify or deflect the whirl or looped systems, but not sufficiently to change the general principle of motion, as a necessary condition of the flow of a cohesive system of matter. I do not see the necessity in all cases of a set form of cycloidal motion, which is most apparent in the changes of flow by the influence of vibration (Fig. 104, page 222), as also in the intermittent local action (§ *r*) in the descending fine column. The principle of the possibility of inducing the cycloidal motions I propose, of longer or shorter periods in a pipe, is possibly the mode used unknowingly by performers on certain forms of horns, where the vibrational period represents the cycloidal space, as I will endeavour hereafter to show,[1] which produces notes of different pitch in the same horn. In any case I anticipate, under all conditions, the efflux of wind from a pipe is pulsatory, and it only depends on certain conditions whether sound is produced or not.

β. If the principles of motion of a fluid through a pipe is hypercycloidal as here proposed, the resistance and consequently the velocity of outflow will be nearly as the circumference of the hypercycloidal loop to its plane of resistance.

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[1] Now postponed for future publication.

91. PROPOSITION: *That a small flat current of fluid will develop whirls of resistance at alternate distances upon its sides. The whirls will form looped or cycloidal systems if they are cramped by nearness of resistant surface, but the current will always tend to enlarge alternate lateral whirls, for each whirl to attain the greatest circular area of rotation.*

a. For the conditions of alternation of whirls this proposition shows that whirls would have a tendency to circumscribe the greatest free areas, 82 prop.; but this is subject to the directive force of the central flowing stream, and is not possible where the friction is uniform or great enough to cause the constant necessity for rolling contact of directly projected lineal parts of the system. Nevertheless, if the current move in a free fluid system by alternation of whirls, first on one side of the stream, and then on the other, the current space would develop the largest whirls, and move thereon by the least tangential friction; and if we make the flowing force great, and the areas of resistance very free, this will be the necessary form of motion. This proposition may be partly demonstrated by the following experiment.

b. Take a white dinner dish and place it in a level position upon a table; pour water into it until the bottom surface is covered for not more than half an inch in depth. Take a pen full of ink or other colouring matter and draw this through the water with moderate velocity, the nib sliding along the surface of the dish. As the pen moves forward in the water a zigzag path formed by the ink will be observed to follow it; which will be at first of about half an inch in width. If we carefully observe the zigzag ink-path by repeating the experiment several times, it will be found to be formed of alternate whirls which are structurally consecutive oblique biwhirls, the one flowing out of the curves of the other, of which the following diagram will represent the directive principles.

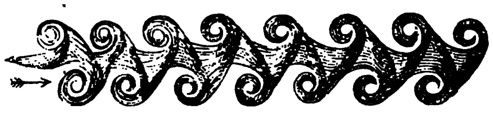

Fig. 134.—Diagram of Biwhirl Deflection in a Uniformly Restricted Current.

c. These whirls will after a short time be distorted by the general influence of motion of one upon the other, but at the commencement of the movement of the pen, a few more permanent forms will occasionally be left when the fluid is nearly at rest. Upon repeating this experiment with a different kind of writing ink to that I first tried, I found that I did not produce the same result owing to the clogginess of the ink. The first ink I used was made of logwood extract and bichromate of potash.

d. The same principles as shown in the above experiment may be witnessed as an influencing cause for the zigzag course of a river, in its flow down a nearly level plane. In this case the river at no time may be assumed to possess sufficient force to cut out a zigzag course such as is found to absolutely exist, but the tendency to attain the greatest freedom of area for the whirls, as proposed (82 prop.), such a course would be the least frictional. If such a system were once incipiently formed by the principles of this proposition so as to produce bays, by the alternate local amplitudes of the whirls, these would also alternately bring the central forces to the margin of the river, and·would cause every bay to become enlarged and deepened at its circumference, until there was formed a channel in the bay in which the river would afterwards be induced to flow, so that it would ultimately change its course and flow through the circumference of the bay. In this case the friction whirls would then immediately be turned inwards and be projected forward to the opposite surface of resistance, so as to induce the formation of another bay on the opposite side of the river further down, or give the river an entirely zigzag course by the alternation of this form of whirl motion.

92. PROPOSITION: *If a small cylindrical jet of liquid be resisted by a less dense fluid, the deflection of the whirls making rolling contact upon the planes of resistances, will be less developed outwardly than in cases of greater resistance, or they may be withheld within the flowing jet by its cohesion, but they will still be motive within this jet.*

a. The superficial film of a jet may be continuous by general cohesion, so that the jet may appear bright and clear, but this is indifferent to the principles of the proposition, as the motive force may be conceived to be active within the circumscribing area of the cylinder that forms the jet, the surface of which is induced to take a reverse direction by the friction of contact.

b. The cases this proposition is intended to meet are the projections of jets of water in air. The same conditions may possibly hold for projections in very smooth fine glass tubes. It assumes that rolling contact also holds in cases of very small surface resistance which I have asserted to be necessary in all cases of contact of moving fluids upon solids or upon each other.

c. That the wind moves the surface of the ocean assures us that a frictional mode of contact occurs between air and water, when the air is moving, and it is quite certain that a like friction will form a resistance to the projection of the surface of a jet of water in air, so that the demonstration of surface friction in the one case will demonstrate it in the other.

d. I had at first some difficulty in arranging an experiment to show that whirl motions would exist in water, moving with moderate velocity through static air, until I thought of making the jet of water extremely small, so that it should present a great surface to the air relative to its very small cylindrical mass, and thus be greatly influenced by the surface resistance, but having conceived this principle of small resistances, my further difficulty was in rendering the motion itself visible, or of obtaining evidence of the same by any means, but feeling assured that motive principles were alike in all moving fluids, whether the masses were large or small, as the many experiments I have given tend to show, I thought it possible that the surface directions of motion of one jet might be observed by directing another jet upon it, as the equilibrium of projection of such fine jets would be necessarily very sensitive.

e. The experiment by which I was finally able to demonstrate the above to my own satisfaction under the condition of a dense fluid being approximately free when reduced to small projectile mass, was, by the interference of two fine jets of water in quiescent air, one of these, from which I most expected to discover directive motion, being sufficiently fine to have its bulk considerably influenced by friction at the surface of contact with the air; the motion of which I hoped to follow by the direction given by deflections after contact upon another jet. I will give my first conception, as I worked this matter out before trying any experiment upon it, which may tend to explain the principles of the experiment I afterward tried.

f. I supposed a whirl system developed in every current as that illustrated, Fig. 129. Therefore, if by resistant contact a fine current were ejected into the air, the air would form a surface of constant resistance, and a biwhirl current or looped system should be induced, within the fine stream, to overcome the surface resistance of the air. Thus if we suffered two fine streams to meet at such an angle that it was possible for one to be deflected from, or towards, the surface of the other, the influence of the whirls at the sides of the jets, as they came in contact, would carry by adhesion the whole small mass of these jets by deflection in accordance with directions of surface motions already induced in them, at least as components of directive influences. That if the whirls in the jet were revolving outwards from the centre by air contact at a point of meeting between them, they would be drawn together, by surface directions acting at the point of incidence; whereas, if no such motions were induced, they would repel each other. Before making any experiment I made a sketch diagram similar to the following illustration of my conception, in so far as I could conceive the matter, by the principles already offered of whirl motion.

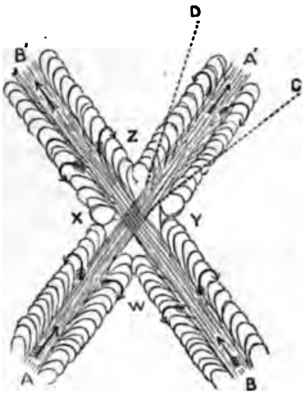

Fig. 135.—Diagram of Theoretical Crossing Jets.

Let A A' represent a fine jet of water projected in the direction of the arrows; B B' another jet projected in like manner across the first. Let these jets by the friction of surface contact upon the air have biwhirl or looped motions already induced within them. Then upon contact of these two jets the whirls at W and X will be drawn towards each other by rolling contact. At Y and Z the whirls would resist each other having opposite directions.

g. Now if such a jet as A A' by its projectile force and the direction of its whirl could enter the jet B B' so as to pass into it, the whirls at Z would tend to direct the jet A A' to D, and the whirls at Y would tend to project the current A A' to C, so that if the current as a lineal system were divisible with small force in its axis, the jet after division, would be divided within an arc included between the radii C to D, directed from the centre of the crossing current.

h. The only difficulty appeared to be some confusion of directions of force lines, which I should have anticipated, except from having made some other somewhat similar experiments on a larger scale, and from the certainty of biwhirl action being constant in such motions.

i. In the following experiment, although clearly founded upon my conception of the biwhirl motion of fluids, which I have before fully discussed, I scarcely expected the full realization of my theory in the projection of one flowing stream through another, and it really surprised me (although I had reasoned it out) as it appeared in practice so contrary to the ordinary experience of superficial observation, so that if I had fallen upon it by chance I should not have comprehended the result. As the experiment for demonstration is very easily performed, I will give the details.

j. Take two lengths of small lead pipe of say half an inch internal diameter, and a yard or so in length. Close one end of each pipe by burring it over, or better still, by sawing the ends of each of the pipes off obliquely, and afterwards closing it over so as to form a cone of about an inch length of axis. The meeting edges of the cone formed in this manner may be soldered together with soft solder. Now after filing off each pipe to a rounded nose, the ends may be pierced with a fine brad-awl or point so as to open them to a smooth bore of say $\frac{1}{16}$ of an inch for one pipe, and $\frac{1}{30}$ for the other. The exact proportions are immaterial. Having the pipes thus pre-

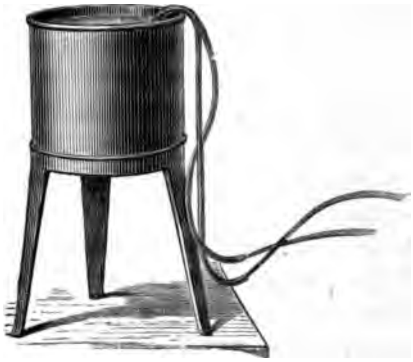

Fig. 136.—Ex.—Crossing Jets of Water.

pared, bend them as shown in the figure above into the form of syphons, and place the open ends in a vessel of clear water at an elevation of about 30 inches above the jets. The free ends of the pipes may then be turned outwards, as shown in the engraving, and be fixed by staples to a wooden stand, each at about six inches from the end; these pipes may be now adjusted by the flexibility of the metal as required. Placing the pipe with $\frac{1}{16}$ inch bore so that it will eject the water nearly horizontally, and the pipe with the smaller bore lower, so that the jet that comes from it will cut the first larger jet at about an angle of 30 degrees, the apparatus is then complete. The pipes may be set in action by sucking them full of water by the mouth. The experiment being now ready, as the jets of water flow, it will be observed that the small jet from the lower pipe will cut a clear way through the larger stream and suffer no deflection at the point of contact, even if the smaller pipe be reduced in size, so that only a small spray of fine drops issue and strike the larger jet, these drops also pass clearly through it without deflection. Further, the larger jet will not be materially disturbed or have any swelling or parting at the point of contact of the smaller one; but the smaller stream will appear as a clear rod of crystal moving through it; however, after passing through the larger stream, the smaller jet will often divide by the whirl forces at points of exit, in which case only the upper part will continue in the direct line of the original projection.

k. It will further be observed in this experiment that the velocity at the point of contact of the small jet upon the larger one is no greater than that of the larger one, as the fall of water is alike in both. The angle of contact of the jets being small we might superficially expect that the two streams would unite and form a single jet, or be deflected from each other, but in this case the small jet striking the larger one suffers only a slight recoil at this point of impact, where the surface particles are revolving by rolling contact upon the air, to be impelled into the larger jet, by the revolution. To accommodate the intrusion of the small jet, the larger one must therefore have its bulk in some way increased, and swell out against the force of cohesion of the water of which it is formed; but the surface of the larger jet being also in revolution by rolling contact upon the air, and this revolution being in an opposite direction to the surface of contact of the smaller jet, it therefore tends to eject it again as soon as intruded, so that the whirls become most unstable opposite the point of contact of the small jet, by which means this is ejected at exactly the opposite point on the larger jet, to that at which it entered; it therefore appears to pass directly through the larger jet without material loss of initial velocity, or in some cases of volume.

93. PROPOSITION: *To every current flowing in a parallel channel or in a pipe, there will be a lateral counter current flowing in the opposite direction near the plane or planes of resistance.*

a. The general cohesion of liquids will always tend to induce continuity of surface, prop. 38 *a*, and in this continuity, the motive effects of rolling contact are still presumed to be active, so that any induced movement from conic deflection, capable of producing a complete cycloidal arc or loop, will tend to give reverse direction to the fluid resting upon the surface of resistance.

b. That by the flexure of traction lines deflected by lateral resistance, a retrograde motion will be induced in a fluid near the plane of resistance, by the principles discussed in 89 prop. and shown in several diagrams.

c. That by principles of conic resistance, simply as head resistance, biwhirl forces induced in parallel channels by the direct resistance of the forward or most free portion of the flowing force, will complete their whirls in direct proportion to the force of projection by which they were formed, in continuing beyond the plane of resistance, so as to produce a retrograde motion upon lateral surfaces as shown, 90 prop.

d. From the roughness and immobility of every solid surface relative to the smoothness and equality of the system of a fluid; a moving fluid in contact with a solid will be more resisted upon the solid than upon any imaginary plane in the fluid, at any parallel distance from it, however small.

e. The adhesion of liquids to solids, where such liquids *wet* the solid, appears in all cases to be greater than the general cohesion of the fluid, and to be generally of the nature of an attraction, 22 prop. It will therefore follow that the conditions discussed, *a* and *c*, of this proposition will not exactly hold if the conditions of adhesion at the surface here proposed be true; as the reflex action by this adhesion would be less frictional at any plane of cohesion throughout the fluid more distant from the solid surface, and the retrograde action would be also less resisted in any less adhesive plane. The conditions of this adhesion were taken in functions of general cohesion in 89 prop., quoted *b* in this proposition. The general equation under these conditions, from surface resistance and reflex action, would remove the retrograde direction of the fluid proposed to a small distance from the plane of resistance, so that if a counter current were formed this would flow the opposite way, *near*, but not directly upon the planes of resistance as given in this proposition. The principles here offered may be shown by a diagram, which may be taken conveniently as a refinement of the functions of biwhirl action of a fluid acting directly upon a resistant adhesive plane solid. I take in this case the action of the projection only, not the traction which completes the curve.

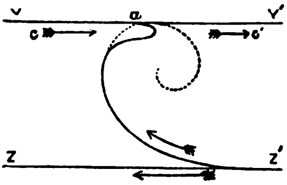

Fig. 137.—Diagram.—Deflection of a Cramped Whirl near a Solid Resistance.

Let Y Y' represent a plane of resistance upon which a flowing fluid is adhesive, in a greater ratio, than the general cohesion of the fluid system.

Let Z' to Z be the direction of a flowing force in a fluid that extends to the plane Y Y'.

Then a whirl of projected fluid deflected from its plane of projection Z' to Z, as shown by the direction of the lower arrows, would in equally cohesive and resisting matter make contact at *a* upon the surface of resistance. But if the flowing force in the whirl be more resisted near the plane of which *a* forms a part, than in other parts of its trajectory, it will be retarded and deflected at this place, and the direct momentum of the following parts of the whirl will carry it forward by flexure to smaller radius, the place *a* now being assumed to be static, so that the reflex action to the direct line of projection would be in the plane represented by the arrows *c*, *c'*, not at Y, Y', directly upon the plane of resistance, but near to it only. If we now compare this matter with the directions given by *tractional forces* to a current near a plane of resistance, we have the same directions given both by whirl forces and by traction as shown

Fig. 126; so that by both principles, a reverse direction of a current should occur *near* a plane of longitudinal resistance.

f. I think the above may be safely accepted as a principle of projectile fluid motion. It may be shown experimentally by the counter currents upon any extensive flowing stream or river, though these counter currents may in this case not be equal on both sides, from an unequal disposition of resistances; but in all cases this may be taken to be a principle of *relative motion* in a flowing current.

g. Perhaps the least demonstrable conditions of a counter current would be in the cramped whirls of a liquid flowing through a pipe, as in this case the reflex action must be brought very near the resistant surfaces. I have therefore sought experimental evidence for this particular case, by giving to the flowing current great velocity, and such an amount of freedom as was possible for continuity of projection, as in the following experiment for which I constructed apparatus. A cistern A, in the bottom of which a brass tube was fixed 2 ft. 9 inches long, and ¾ of an inch in diameter. A boss was soldered on the brass tube at about 9 inches from the lower end, and a small hole drilled through this into the tube, the hole being made smooth inside. A small glass tube was inserted, and bent as shown in the sketch. This was about 6 inches long, the lower end was inserted into a vessel of water B. On filling the cistern and allowing the water to run away freely through the brass tube; the water was drawn up from the small vessel so long as the flow continued. This experiment is similar to one of Venturi, wherein the pipe is placed at the *vena contracta*, but this position, shown by Venturi, is entirely unnecessary for the effect. This same direction of motion in the small tube takes place in both cases, which I take to be evidence of the presence in the pipe of a counter current throughout its length. This experiment may be also used as a demonstration, that the flowing liquid does not *fill* the pipe entirely, but leaves space for intermittent action, as proposed, 90 prop., sufficient to include the small current flowing upwards from the vessel B. The pipe B may extend to the depth of the outlet or deeper with like effect; or the system may be placed horizontally, the like evidence of suction being in all cases present.

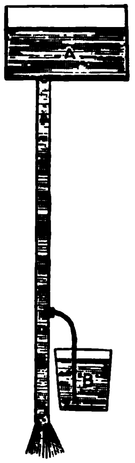

Fig. 138.—Ex.

94. PROPOSITION: *A flowing fluid in a channel will be deflected from every resistance by motive whirls until the greatest volume of the flowing fluid moves in the tract most free from resistances by equilibrium of rolling contact.*

a. Demonstrations that a liquid will be deflected from a resistance in cases where there is not continuity of planes of adhesion in the direction of the force were shown 42 prop. It is evident also, where there is continuity of solid surface, and the projectile force of the fluid is sufficient to overcome the adhesion to the solid. I will take both cases.

Let a stream of water, say of half an inch in diameter, fall vertically as from a pipe, and place in this at an angle to the course of the stream the edge of a razor, so that half the current may pass free, and half be deflected by the surface presented by the side of the blade of the razor. By the resistance offered to this, the stream will swell out slightly half an inch before it reaches the edge of the razor, and by the general elastic forces in the flowing system, which will be conserved after passing the resistance (39 prop.), will fly off from it.

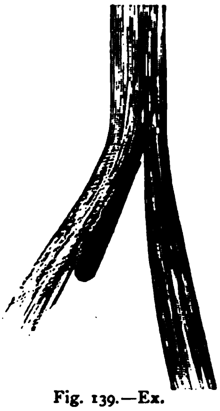

Fig. 139.—Ex.

b. For the demonstration of projection under the influence of surface adhesion we will permit an undercurrent to enter an open parallel channel; in this case it is clear that the central area of the upper surface will be the most free part of the channel from near resistances. Experimental evidence may possibly be made more conclusive by a celebrated experiment of Bossut, which is as follows:[1]—

A reservoir of water of about 11 feet in height is kept constantly full or at one level surface. An orifice is made in the vertical surface near the bottom of the reservoir; the opening being five inches wide horizontally; the depth being adjustable by a brass sluice valve, which can be opened to any required distance from quite close to two inches by the movement of an adjusting lever. A trough or canal 105 feet long, 5 inches wide inside, and 8 to 9 inches deep, is placed at the orifice quite horizontally, and the bottom of the orifice from the reservoir is in a line with the bottom of the inside of the trough. The sides are also in a line with the edges of the orifice. The trough is made of strong fir planks polished inside, with quite smooth joints.

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[1] Abbé Bossut, *Traité d'Hydrodynamique*, vol. xi., pages 196 to 206.

c. In the experiment I wish to notice, the sluice is opened exactly half an inch. I translate Bossut's words: "It is necessary to observe that in every experiment the velocity of the current is not uniform, that is, that each separate division of the canal will not be traversed in equal time, and that the velocity diminishes as the water recedes from the reservoir. This movement has some particulars which merit observation. When we raise the sluice the water is ejected along the bottom of the canal, and at first keeps only in this direction. But as it proceeds it meets with resistance, swells on itself, and its surface takes the form shown by dotted lines in the above engraving E M G. Then it falls by its own weight from the highest point M, and *a part of the water returns towards the reservoir*, following the direction M N. There is, therefore, in the part C M of the canal two currents which are going in different directions—the one formed by the deeper water which goes in the direction C F, and the other by the surface water which returns in the direction M N, and which is very apparent at the commencement. This effect terminates at a point N at about 12 feet from the orifice E C. Little by little the swelling of the water diminishes, although it always exists, until finally it takes the form of the water represented in the engraving E R G, where the point R is the highest from the bottom of the trough. The water which arrives at each instant from the reservoir strikes continuously at N O, the mass before it, N O F G, mixes with it, and forms the mass which renewed incessantly returns to the same figure. The currents of which we have spoken are forcible examples of those which form in rivers or the ocean, in all instances where the water is retarded by obstacles. We see in this case that the water swells at first and then its weight

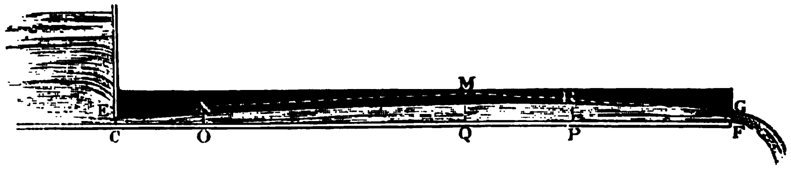


Fig. 140.—Ex.—By Bossut showing Reverse Surface Direction.

causes it to spread itself out, from which it results that currents may take any possible direction."

The motion of the water in Bossut's experiment may be explained upon principles of resistance, in the following manner. For the general flow of the current the central surface horizontal plane would offer the least relative local resistance, whereas the surfaces of the trough would offer local resistances in proportion to the pressures upon them, and the air surface would offer a certain small resistance at its line of contact. The current would, therefore, be deflected to form contact whirls in every direction, upon which the flowing force would ride by rolling contact, but as the local resistances would be less upon the upper surface than upon any other, the general whirl force would deflect the current mostly upwards and cause a general central elevation.

d. For the entire resistance to the flowing mass, not local and transverse only, against gravitation, we may take it that the greatest amount of resistance would be from the surface of the bottom of the channel, by which every particle of the liquid would be retarded by that in front, 42 prop. It would, therefore, occur, that the stream in its flowing force would have a constant tendency to split upon the head resistance, and upon principles of conic resistance, to have its force deflected by the local side resistances, so that whirls formed by the general system of resistances would curl over and roll backwards almost frictionless upon the eentral part of the stream opposite to its general flow.

e. Now taking the directions of the surfaces of resistance that surround a flowing liquid stream, the aerial surface must in all cases be nearly the area of least resistance. In the case of the trough it would be particularly so; therefore we have a much greater force of adhesion of the water to the bottom. Now from any cause whatever a moving fluid actually moves away from points of resistance to the point of least resistance offered to it, as our proposition states, therefore in this experiment the air presenting little resistance, the fluid would move into this with all the energy its internal accommodation permitted. This energy may be computed by the amount of matter it would be able to carry against gravitation. Having this plane of least resistance, at the aerial surface, presuming that there is an increase of resistance with depth of water from nearness of the bottom, the liquid would take a rounded form upwards in the air. The mass carrying this force having moved to the surface of the ld not again *sink below it*, as in order to do so, it woul e to points of *greater resistance*, which is impossible fo y, and especially so for a liquid or fluid of any kind tha hin its own matter great solidity of resistance. There t of the body which has now received the impresse forward with the stream, but the part which impresse fers reflection and returns with its reflected force, accom he impulse of natural gravitation, from its now elevate surface motion back in the reverse direction to that i originally projected.

s experiment shown upon the principles of the propos be represented by the diagram below:—

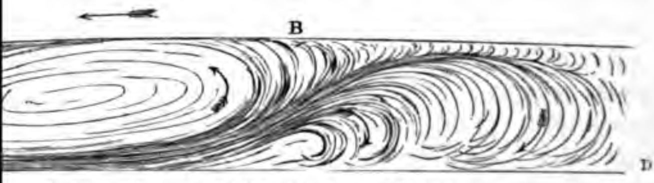


Fig. 141.—Diagram—Whirl Theory of Bossut's Experiment.

m projected along the bottom of the channel toward D ed by the resistance of the channel to B, where an hirl is formed; from the centre of the oblique biwhirl e reflex current falls by whirl force and the potential of o C.

d at first sight appear from the above that an undercur- ot exist, as the resistance would carry the greatest motive

CHAPTER VIII.

PRINCIPLES OF MOTIVE RESISTANCE TO THE PROJECTION OF FREE SOLIDS IN EXTENSIVE FLUIDS.

95. Preliminary remarks.

a. Having fully discussed in the previous chapters the principles upon which motive directions are given to fluid forces moving under the influence of solid resistances, which are shown to produce similar or equivalent deflections in whirl-forms, complete or incipient, in all cases; it will now only be necessary, as regards the projection of solids in open fluids, to consider the conditions under which the fluid has greater freedom to complete its motive force lines by the uniformity of mass resistances in contiguous parts. This matter, although I know it to be an important part of my subject, as it concerns the impulsion of ships, I have been unable to investigate as I wished, and I can only direct attention to certain particular conditions, relative to previous propositions, which may, I think, be usefully followed as principles.

b. I have endeavoured to demonstrate by theoretical deduction, as also by experiment, that when any particle or unit mass is projected in a fluid which may be conceived, as regards the unit projection, to be of infinite extent, that the projected unit will engender within the extensive fluid a conic area of resistance, and cause lateral deflections of the forward parts of the fluid (58 prop. page 170), which lateral deflections produce annular whirls, if central to a mass, or biwhirls, if the fluid impressed is a plane (77 prop. page 219).

c. It is also affirmed by other propositions that the same principles of motion, or their equivalents, will engender whirl motion in the projectile unit itself, if this be a fluid, as shown in the single drop (66 prop.); and the same motive forms are also observed in the projection of liquids in pipes and in jets, of which instances are given in the last chapter, but more particularly in 90 prop. In the consideration of the projection of fluids within fluids, taken in chapters 5 and 6, all parts of the projectile and the resistant are evidently alike mobile. In these cases, by principles of conic resistance, whirl systems are induced which diffuse the unit projection entirely and extensively within the resistant fluid. In the case of the projection of a solid, we have a simple unit, held by its cohesive forces constantly under motive restraint, and this being of fixed form, all resistances and motive directions for accommodation of fluid forces must therefore occur wholly outside this, that is *within* the surrounding resisting fluid, so that by this principle of motion, we must conclude that comparatively to the motion of a projectile fluid previously discussed in these pages: *That a solid projectile body moves in a fluid under the impression of forces that would have separated its mass, as a projectile fluid is separated, if it were not held under the restraint of its cohesive force.* In this manner we may, by principles already discussed, fairly estimate the natural strains from the direction of forces active upon the solid, and contra to these, the strains and directive forces that are taken in the fluid to resist them.

d. We have further a most important condition evident by experiment in the projection of a solid in water which renders the projection of the solid in a certain degree equivalent to the projection of a fluid, namely, that the water is so powerfully *adherent to the solid and cohesive in itself*, that the solid carries with it in its projection a considerable portion of the contiguous liquid also. Therefore we must conclude that the solid and contiguous liquid form in a certain sense *one unit projection.* This contiguous liquid part of the projectile system, when the velocity of the projectile has been maintained for a certain time, forms no mean factor of the entire projection. This is made quite evident by the important experience of Mr. J. Scott Russell given 34 prop. *d* page 116, wherein the projection of a boat in a canal engenders a motion in a mass of contiguous water that possibly quite equals the boat in volume-force; which is made evident by suddenly stopping the boat, which represents one factor only of the projectile system. The liquid in this case by its internal mobility continues a certain part of its projection after its frictional detachment from the boat. By this theory of projection of a united solid and surrounding liquid system, being assumed to form one unit of projection, we may conceive also that motive forms of whirl, or other systems, may be induced by the liquid part of the projectile within the resistant liquid. This principle will offer much less frictional modes of motion than those that would be produced by any form of slipping or gliding motion, if such were possible; and will bring the condition of solid projection much nearer in principle to fluid projections than would be possible if the evident adhesive and cohesive action between the solid and fluid were to be entirely overcome at the surface of the solid.

Equilibrium of forces about a solid projected in a liquid.

96. PROPOSITION: *As a body placed in a liquid will be surrounded by equal pressures at equal depths of the liquid; this body, if moved horizontally, will after the first impulse encounter very little greater head resistance than it will receive pressure from behind; but as the body to continue its motion must displace a certain bulk of the liquid from the front to the back, the force required for the continuity of its movement will be as the friction of this displacement.*

a. From the general instability of fluid matter by which near particles under the impression of small forces may move quickly to equilibrium; moving masses slowly impressed by constant forces might attain motion with very small resistance where the general surrounding equilibrium was not much disturbed. But as higher local velocities were attained, the accommodation could not be so immediate, and the compressions engendered by the forward motions would extend in the fluid to much greater area and move in this area with less freedom until the resistance might approach the general conditions of the elastic reactive forces of a compressed fluid. Where such a system would not offer the entire solution for the effect of a given forward fluid resistance, is that the fluid being an elastic system of freely jointed matter, the resistant parts would by deflection under the compression attain set directive motive forms of projection, which would be those in the path of least resistance for the displaced fluid to move to the position of the displaced solid projected therefrom. These displaced parts would have also directive energy, and produce, as I will hereafter show, rotary systems of motion in the fluid, consistent with the velocity of the moving body, which, by deflection of the fluid to backward parts, would either *increase* or *decrease* the general resistance to forward progress of the solid. In this manner the resistance to the motion of a body in a fluid would be proportional to the powers of the set motive forms, either to assist or interfere with, the system of accommodation that it would be possible to set up for its impulsion at a certain velocity, and not as a function of the *transverse section* presented to the adhesive fluid resistance. The motive forces engendered in the fluid about the solid would form a part of the system of general projection as before stated, and these forces would be active upon the projection of the solid, into the resistance according to the directions of motions induced.

b. The researches of Messrs. J. Scott Russell, Rankine, Froud, Stokes, and others, have demonstrated that certain forms of vessels will offer less resistance than other forms, these not being necessarily proportional to the volumes of displacement. These conditions. will be better developed by future propositions. This proposition need only be taken in a very general sense.

Projection of whirl forces by free solids moving in fluids.

97. PROPOSITION: *That a free solid moving in a fluid of infinite extent will carry forward with its motion the nearest portion of fluid in front that resists it, and with this portion, will open out a cone of resistance in the fluid and engender whirls, that will by their rotation ensure rolling contact upon the general mass of the resisting fluid.*

a. If a solid move forward in water it must of necessity occupy the space formerly occupied by water, and as the water remains during the movement at nearly the same level at its surface, except for such small differences as I will hereafter consider, it is clear that a certain quantity must be constantly moved from the forward to the backward part of the projectile solid, as discussed in the last proposition.

b. The pressure upon the water by the movement of a solid below its surface, upon the above conditions, will in every way resemble the pressure of water upon water, because I infer that a certain volume must constantly be moved forward by this pressure, that is, it must move until it is displaced by the solid as given, *a* above. Now if such a volume be pressed forward this must act in its pressure exactly as though it were a projectile current of water, and the same forms of motive resistance will be engendered in the resisting water as were shown in principle in 73 prop., page 209, except, in this case, that the projectile fluid will be held under a certain restraint, by the presence of the near solid to which it will adhere with a certain force.

c. It may also be conceived from previous experiments, that the water at the head of a moving solid, as, for instance, a boat, will impress the resistance of the extensive fluid in front, which offers by surrounding hydrostatic pressures conic resistance, upon principles given in 58 prop. This form of resistance is also evident under conditions given in 40 prop. *b* of a peg in a stream, the water in this case being motive, which is equivalent to the solid being motive, the liquid being in both cases elevated at a distance in front of the solid, or in the place where the motive resistance is deflected. It is also clear, as before shown, that such a solid as a boat cannot separate its own mass upon the conic resistance, except in so far as it is a system of motion including the fluid carried with it of which the liquid projected in front forms a part. Therefore after a certain amount of deflection of the water carried forward by the boat, which is displaced, the boat then enters the cone of resistance by a motion that is practically a fracture of the resistant cone in its axis.

d. In the above case of fracture of the cone of resistance by a solid projectile, the projectile will encounter the least resistance in its lateral parts and near the aerial surface of the water, particularly for impressions of forces from the boat at positions below the surface of the water. Therefore into the smallest resistances or weakest parts of the aerial surface the projectile forces in this case will be deflected, and towards the weakest points of resistance the projectile water carried by the boat, will be best able to complete such circulatory forms of motion as are necessary to ensure rolling contact to its projection. It will also follow that as all parts of the aqueous system have equal density, that in proportion as the head of the boat by its forward protrusion penetrates the water below the surface, the cone of impression formed by resistance of the moving water in front of the boat will be more resisted; since the surface will relatively offer but little resistance to the conic areas directed from the stem of the vessel. The deflection of the water therefore by the minus resistance will be towards the surface both forward and laterally, so that the whirl system formed at the surface will be in the plane of the surface nearly, or *biwhirl.*

e. The visible evidence of the generation of a projectile biwhirl system about the head of a boat in full motion will be seen by the conic pressure at the surface of the water at the bows of the boat,

the forward water from the boat laterally immediate
es in contact with the full resistance due to the pre
level surface of the water. This is exactly equivale
of the water before the peg in the stream (40 pro
If the whirl force did *not* deflect the water from t
oat, but that the boat came upon the resistant wat
mpression, then the mass of the water in front wou
ve the general surface directly at the head of the bo
ave is elevated when it impinges upon a solid vertic
r surface of resistance; the elevation being in dire
immediate compression upon the nearest part of t
ce water about the area of contact.

bove principles the constant forward motion of a sol
l as constantly overcome the forward liquid resistanc
ns of deflections it induces. This continuity of projec-
ble the constancy of projection of small forces given in
erein the projection deflects the whirl backwards, or more
king leaves it behind in continuing its direct forward
e conic resistance separating the projectile force in a
ea, as is shown in the engraving Fig. 100, page 216,
irl-ring is left behind.

me manner the forward projectile whirls from a solid
hind if the solid be constantly pressed forward with a
e. Therefore this fact will open out to us a method of
projectile whirls engendered by the forward motion of
may make the solid so short lineally to the direction
ion, that the whirls will be separately developed, and

i. The experiment I tried was as follows:—a trough 20 feet long, 11 inches wide, and of the same depth, was filled 9 inches deep with water. A piece of board of convenient size to hold in the hand, 15 inches long, 5 inches wide, and 1 inch thick, was held upright in the water in the trough near one end; the end of the board being sunk about 6 inches below the surface. This board was moved along at walking pace, keeping it vertical and at equal depth. The whirls induced by the forward pressure could be clearly observed deflected behind the board and moving backward to fill up the space of displacement. The general forms and directions of these whirls are shown in the engraving, Fig. 142, which is taken from an angular solid made in section to represent the head of the boat. In this case the whirls that are thrown behind the projection are not spread out as in the case of projection of small forces previously shown Fig. 102, page 221, as the surrounding forces are not quiescent but laterally motive relative to the projection, from traction of the water behind the projectile solid. The conditions of the whirls as following forces I will hereafter consider, the present proposition is used for the demonstration of the existence of whirls *simply* being induced by the displacement of solids in fluids.

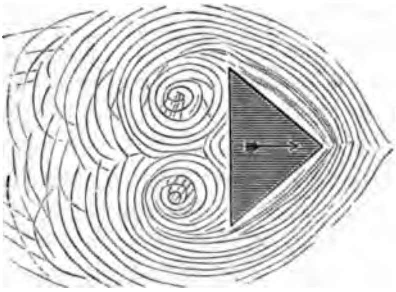


Fig. 142.—Ex.—Evidence of Whirl Motion by following Whirls.

98. PROPOSITION: *That a free solid plane moving longitudinally in an extensive fluid will engender projectile whirls in the fluid by adhesion of the fluid to its surface, such whirls will form means of rolling contact to all lateral resistances in the fluid.*

a. The principles of lateral resistances discussed in props. 88, 89, and 90, will answer for the present one, except where conditions of restraint are pointed out in these propositions, in which projectile solids in an extensive fluid will, from the fluid being more free from rigid resistances, cause the motive lateral forces to be developed upon a larger scale as more free whirls.

b. If we consider the solid plane of resistance shown Fig. 121, page 249, as a *projectile* plane relatively to the motion of the water. This plane in moving forward will produce exterior pressures at a distance from its mass by conic areas of equivalent projection to the cases of resistance previously discussed (88 prop.).

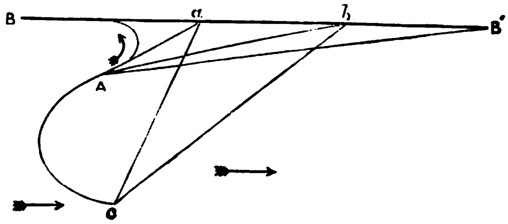


Fig. 143.—Diagram—Conic Deflections near Motive Solids.

c. Taking the diagram given Fig. 121 to represent the part of the diagram above B B′ A; A being the point previously taken for the extent of resistance in fluid moving parallel to the plane of resistance upon B B′, which resistance, as regards forward parts, was shown to be derived from conic areas of adhesion A *a b*, A *b* B′, the flowing force being by the resistance thereby deflected in the direction of the incurved arrow as shown near A, turning the current inwards towards the plane B B′. In the case discussed in 88 prop. the point of resistance of the central area or most free part of the current was assumed to be only at A. If we now take the case of an infinitely free fluid, the lateral resistances may be assumed to extend to any distance, but the values of the forces, derived from the angles of effective resistance, will decrease in like ratio. Thus if we assume a distant point *c*, and take the resistance of the same surface as before taken *a b*, this oblique cone in an infinitely jointed cohesive system of matter will offer much less resistance to the motion of the plane B to B′ in ratio of its constantly increasing angle of divergence from the direction of projection. It will also be seen that the diagram, Fig. 121, shows in this case the same form of directive lines as that given in Fig. 136, page 272, and the same forms of motion as given in 93 prop. will be necessarily followed in this form of projection as in that in a restricted area, except for the effects of deflection due to the restraint, in the closeness of area previously considered, in the one case.

d. Upon the above principles of conic projection it will be seen that a moving solid in a liquid, particularly after it is surrounded by established whirl forms, will not have the deflected liquid which it opposes thrown up against it as a wave against a sea wall, but the moving solid will rather by conic projection press the liquid back from its surfaces of contact into lateral space.

e. If the adhesive whirls upon a moving side surface are *projectile*, the fluid in contact will be projectile, therefore for a moving body to continue its projection in a fluid there must be means of supply for such projection. In this case we must imagine some of the conditions given 90 prop. as active, and consider that the surface receives supply at such positions as are most free from projectile whirls, or from fluid forces otherwise directed, to enter the system of motion; the condition of which will vary under different circumstances.

f. The best means that I can suggest, to ascertain the presence of projectile whirls being thrown off the surface of a solid moving in a fluid, would be to endeavour to measure the loss such fluid sustained near the surface of the solid by the whirl projection, in some particular case, where the supply of fluid could not be brought, or could be brought only by a very frictional course, so that the deficiency would indicate the consumption of the fluid in whirl projections. This would no doubt be difficult to do directly, but by restricting the supply of the fluid to form the necessary whirls, by any means, this restriction would possibly produce a strong impulse to draw the fluid towards the static plane of rest upon which it must be motive by rolling contact. This may be perhaps best shown by the principles discussed 51 prop., page 156; where it is shown that it is mechanically possible by whirl systems, which are there described as volutes, to continue a force of projection in a fluid without great loss of velocity by constant disintegration of a part of the flowing force to form the involuted system of the whirls.

g. It will also be clear that if in the projectile whirl system of a solid and a fluid, whirls are thrown off in the fluid and carried forward by the solid moving longitudinally, as a necessary friction-saving motion upon resistances at parallel distances, that the friction of a moving plane will be greater than that of a moving fluid in a current of like extent that could supply freely such a whirl system as that shown 51 prop. *c*, from its own mass.

h. Accepting the above, if we move a solid body having a plane under surface over and parallel to another solid plane of more extensive area, between which planes there is intervening an equal depth of liquid; the moving body with its adhesive liquid would then form one of the planes capable, as previously discussed, of engendering a projectile whirl system in the intervening liquid, tending to throw its whirls as shown in the last proposition, Fig. 142, out of the motive system at the back of the solid projection. So that if, as is the case, the projectile solid is unable to supply from its mass the necessary fluid whirls to secure rolling contact, the intervening fluid will be projected backwards or some other very frictional mode of supply must be induced, as that of a gliding motion.

i. By previous theory I have assumed in all fluid motions that sliding would be excessively frictional and that rolling contact would be almost the only possible form of motion for the movements of fluids upon themselves or upon solids. Therefore if the system of rolling contact is persistent in the case proposed, for the contact of the liquid upon the resistant surface, the *direction* of such motion will be persistent also, excepting as it is withheld by restraint or by some other force.

j. In this manner we might theoretically separate the effects of the action of the two solid surfaces between which a resisting fluid is placed, and assume that so far as one of the surfaces of the moving solids is concerned, that the intervening fluid would supply all necessary matter for integration, thus forming the whirl system of rolling contact, as assumed to be the least frictional on *one* of the planes. In this case, supposing the intervening liquid disintegrated by rolling contact upon the lower surface of resistance, that is, upon the bottom plane, and that a motive solid is placed above this, which will evidently be unable to supply liquid for this disintegration, it is then quite clear that if there is no direct means of supply of the liquid for whirl production, that the upper plane, that is the solid, would be forcibly drawn down to supply the deficiency of fluid matter to form the friction whirls. We ought therefore to be able experimentally to obtain evidence of the truth of this proposition by the motion of any solid parallel surface moving at a limited distance over another like surface with any intervening fluid body whatever filling the interspace.

k. To obtain experimental evidence of this proposition we may assume the following conditions:—that a boat carrying an adhesive liquid with it, and moving along a stream would engender a system of projectile whirls by constant friction upon the bottom of the stream, upon principles already discussed; and that the whirls thrown off from the liquid which was adhesive to the bottom surfaces of the boat upon conditions similar to the volutes of 51 prop. would be retained with certain force upon the bottom surface of the stream, and if there were no frictionless exterior means of supply of water, that the boat would follow the projectile direction of the whirls, as a part of the flowing force of the whirl system, and be drawn downwards.

l. For experiment the following was arranged:—A boat-shaped log with vertical sides and a perfectly flat bottom, of 18 inches in length, 5 inches in width, and 3 inches in depth was made out of a solid piece of wood. The top and bottom surfaces were therefore flat and of equal dimensions. A piece of sheet-lead was nailed upon the entire bottom surface so that the log-boat was in stable equilibrium within the surface of the water. The upper surface of the boat floated at about half an inch above the water line, horizontally. A piece of string was now attached to the upper surface of the log-boat by means of a nail, so that the boat could be drawn along the trough. Placing the boat upon my trough, 21 feet in length, previously described, which contained 8 inches in depth of water everywhere throughout its length; I now held the string at an angle of about 30 degrees to the surface of the water and drew the log-boat along with it, after me, at walking pace. In observing the boat I found that the upper surface immediately sunk to the level of the water, notwithstanding the force that I used to draw it along, was tending to pull it *upwards*. When I quickened my pace a little the entire boat sunk beneath the surface of the water. The point by which the boat was drawn in these experiments was directed to the centre of inertia of the boat for the angle taken, so that the log-boat remained approximately horizontal throughout its movement.

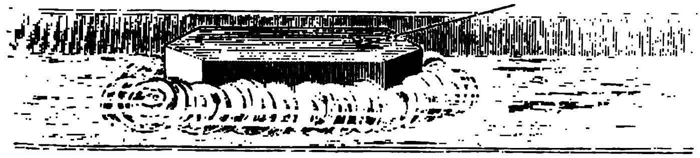


Fig. 144.—Ex.—Evidence of Projectile Whirls about a Solid.

m. The above diagram was drawn to represent this system of motion according to my theory. The boat is shown in the engraving much too high above the water, and the whirls do not appear to extend to the lower surface of the trough which they should do. I suppose my sketch for the diagram was not very clear, but anticipate the engraving will sufficiently indicate the principle. This motion of the boat downwards would be entirely anticipated upon the principles discussed for the directive influence and energy of projectile whirls by lines of rolling force engendered by its motion under the conditions given, but I do not see how it could be accounted for by any other system elsewhere proposed. If the water could slip or glide upon itself or upon the boat, gravitation being constantly equal, the boat would move ***upwards*** towards the direction that it was pulled by the string, and not sink ***downwards*** as in the experiment given.

n. It may be observed that the restrained curves of fluid force discussed above, would have their functions materially changed by any other form of boat than one with a flat bottom and vertical front. Thus suppose there was a directive angle in front as we observe actually in ordinary boats, the surface water would then be deflected downwards by this angle, and the deflected water would supply the necessary material for friction volutes (51 prop.). In this case quite the reverse effects would be observed, for instead of friction of contact consuming and throwing backwards the fluid between the frictional planes, it would be introducing fluid between them by continuity of contact upon the lower surface of the boat, and thus cause the directive angle to draw in water to maintain the whirls upon which the boat would ride, and be therefore ***emerged*** instead of *submerged* by any increase of velocity. In this case also, the resistance from the greater power of inducing whirls of rolling contact by the deflected plenitude of material at the head of the boat, the friction would be considerably reduced, that is if the velocity were within the ratio of possible accommodation in the liquid for this form of motion.

o. By the above principles, to attain the least friction for the impulsion of a boat of a given volume, it should be built in no part parallel to the direction of motion but rather of ellipsoidal form. The whirls formed at the forward parts should complete their projections on the backward parts with re-entering curvature. This will also meet conditions I will point out further on.

99. PROPOSITION: *That the lateral whirls upon a moving plane in a fluid will be developed to the greatest amplitude at a certain moderate velocity. That at lower velocities the fluid will find accommodation for whirls of smaller projection. That at higher velocities the projectile forces will separate the cohesion of the fluid system and cramp the whirls. The resistance will be to the velocity inversely proportional to the amplitude of the whirls.*

a. That an infinitely jointed system of matter would move by very small forces the near parts, and by moderate forces the distant parts, was discussed by the conditions of a hanging chain (53 prop. *b*, page 160), wherein it was shown that a small force when first impressed on the lowest link of the chain would move the lowest link only, but a larger force would set the whole chain in motion. It was further shown that a force at high velocity would also move the lowest link, that is, it would move upon its nearest free part or axis, as the inertia of the near part would be entirely overcome without materially disturbing that of the whole jointed system. The like conditions were also shown for a more rigid jointed system as a pile of single bricks in 53 prop. *d.*

b. Principles equivalent to these may be assumed to hold good in the generation of lateral whirls about a solid plane moving in a liquid longitudinally; so that in the impression of intense forces the system of possible accommodation in the fluid may necessitate separation of the molecular parts from their systems of continuous jointing, to produce a motive displacement that may contain certain elements which are nearly equivalent to fracture.

c. The whirls from a projectile surface moving laterally in a fluid will be generally developed proportionally to the force of projection, and the freedom from lateral resistances conjointly. The friction of resistance to the fluid will be for the most part distributed in area, that is, where the whirl system can take the greatest amplitude; but if the system of rolling contact can be equally developed without great friction in a smaller area, there will then be less inertia of the surrounding fluid to overcome, in order to induce whirl motions, and the entire motion will be also less frictional in such slow projections.

d. For the conditions of the slow projection of a plane moving longitudinally in a liquid, we may be assured, that as the solid will possess only a certain length of plane, the *flow*, as we may term it, of the liquid that is adhesive upon this plane will only engender a motion for a certain distance laterally in an extensive fluid; for this contiguous fluid, considered as an infinitely jointed system of matter, will move under slow motions by accommodation within its near parts, within such space of diffusion as that in which the distributed projectile force will be best able to overcome the inertia of the resistance of the mass of the static fluid. Therefore we can imagine that in the projectile whirl system of a solid moving in an extensive fluid, if the movement be slow the whirl projectile force will be *weak*, and not widely distributed against the resistance or inertia of the liquid; and that under such circumstances, the resistance will be *less*, from the smallness of the whirls necessary to be produced to ensure rolling contact, that is, than it would be if the projectile amplitude of the whirl were such as to carry the projectile force into more extensive space, to move a greater mass of the contiguous fluid.

e. Upon this principle of lateral whirl projection, the projection of a solid may be resisted more or less than in proportion to any direct function of velocity-projection of the solid simply, or as the amount or weight of fluid to be displaced; and thus the velocity of a boat in relation to the propelling force used to project it in the water, may be more or less than any given function of the force employed. This condition of development of small friction whirls here proposed, will be the condition of any slow constant projection when small disturbance only is evident, as in the projection of a boat at low velocity on smooth water, when the surface of the water is undisturbed at a very short distance from the boat.

f. We may now consider another case, given in the proposition, of projection entirely different from that discussed above, where the velocity at which a solid moves in water may be such that it will overcome the *cohesive force* of the water entirely, so that the water will be *fractured*, or separated into such forms of motion as philosophers have considered for the conditions of gliding motions. I do not believe such forms of motion as *gliding*, can by mechanical means be produced about a ship by known forces possible to be applied. But certain high speeds may approach the principle of this form of motion by restraint of the whirl-forming space, as was shown in principle by instant impressions on our hanging chain just referred to, where a system moves by intense force on its nearest joint, so that this near motion may be taken practically to be the same as a motion of projection for very high velocities, such being also a motion in degree equivalent to fracture, or release of instant near cohesion, that the general *principles* of *fracture* may in a certain small degree hold; and that as far as the fracture is concerned the body will be free from all further resistance, and its velocity relative to this fracture be as of a free body. But if we imagine partial fracture to occur at very high speeds by lineal displacement, the projectile body will be only *more* free for extreme velocities, as it will encounter less relative resistance by the amount of partial fracture of the cohesion of the liquid, than will occur in moderate velocities in which very extensive whirls are developed by the continuity of contact of cohesion in the system.

g. If we admit the partial conditions of fracture, or the possibility of this as equivalent to a restricted case of gliding, then whirls engendered by a motive surface acting upon the resistance of a fluid may, from insufficiency of time, be imperfectly developed in the distance or in such a manner only that their curves would be cramped, and return by a small radius to the surface of the moving body. Then in the near distance the fractured parts of the fluid system may be assumed to be separated from the fluid mass, and the velocity of the moving body suffer less restraint proportionally to the amount of fracture produced, which will be really in this case less inversely as the radius of development of friction whirls.

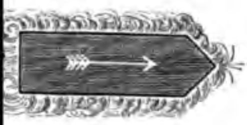
h. Assuming as a separate condition the movement of a solid in a fluid to engender forms of motion in the fluid that are the least frictional, at the velocity at which the solid moves, and that induced motions always have a tendency to continue, so that long surfaces will offer less proportional resistance than short ones per area; then upon purely theoretical grounds, to recapitulate the whole matter considered, the value of side resistances might be estimated as follows:—

Firstly, if the motions be slow, whirls of small amplitude would be engendered, causing small displacement of the parts of the fluid upon themselves, or if very slow, such ample time for accommodation would be given, that the solid might be conceived to roll forward upon very small masses, or even upon molecules only.

Secondly, in motions strictly within the velocity of the continuity of the power of adhesion and cohesion of the fluid, whirls would be engendered of extensive proportions, the evidence of their existence being visible at the liquid surface by the projection of ridges, or waves formed laterally upon the surface; which ridges by reaction

form the planes of resistance upon which the whirl system
s makes rolling contact. This velocity would be pro
y very frictional from the volume of matter moved beyond
ssed above.

, the possibility of a high velocity at which the whirl
rease in amplitude by fracture, or cramping from want c
omplete their forms, so that they spread out less relativ
in extension of the motive system. The following dia
ll express types of these ideas, of which, on account c
urbing causes, I am not entirely confident.



45.—Diagram—Slow Projection.

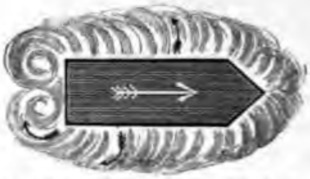
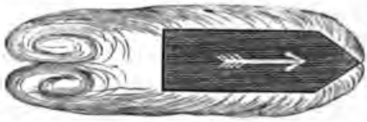


Fig. 146.—Diagram—Moderate Projection.



100. PROPOSITION: *That the system of whirls established about a solid moving in a fluid are projectile forces which can only be brought to the equilibrium of rest by equal resistances.*

a. It was shown in 34 prop. *d*, that the contiguous liquid forms a part of a projectile force with any solid moving within it by adhesion; as demonstrated by the stoppage of a boat in Mr. J. Scott Russell's experiment before alluded to. If we assume in this case of a projectile boat, that whirls are engendered in the surrounding liquid by that portion of the liquid which is carried forward by adhesion to the boat, these whirls will then, by the uniformity of the surrounding resistances, finally assume *set forms* which will be those that are the least frictional in movement, and these forms will therefore remain persistent. Now by the continuity of such motions in which the uniformity of resistances assume a sort of motive quiescence, the whirl forms could not be *observed*. But if they are really projectile forms as here assumed they could be made evident by offering greater resistance at some part of the induced whirl system. This principle I have endeavoured to investigate experimentally as follows:—

b. Using the trough before described which measured 20 feet long, 11 inches wide, and of the same depth; and a log boat made of a piece of solid wood 18 inches long, 4 inches wide, and of about the same depth. The trough was placed in a level position with about 8 inches of water in it. I drew the boat along the trough by a piece of string, at walking pace, for ten feet or so, and then caused it suddenly to stop, by means of a bar placed across the trough above the water line, with which the head of the boat came in contact. In this experiment the side whirls continuing their induced momentum,

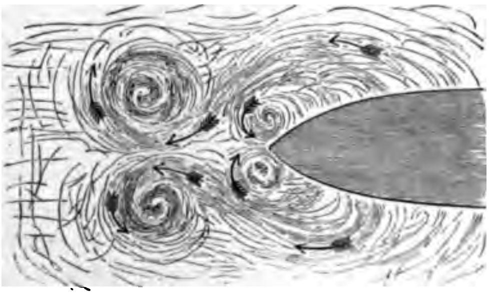


Fig. 148.—Ex.—Reversal of Lateral Whirls.

derived from the projection of the boat, were thrown off by the sudden concussion, and projected forward with some velocity. This projection of whirls appeared very evident by careful observation, as the whirls formed when thrown off formed two distinct whirlpools, at a distance of about fifteen inches in front of the stoppage; where previously to the stopping of the boat the water was quite smooth and undisturbed.

c. The adhesive system of water upon the boat appeared to unroll and reverse the whirl direction as it existed upon the side of the boat when in projection. This reversal may be made quite apparent in some cases by observation of the surface motions which in this case somewhat resemble the following whirls, before described, in their natural forms for the near part; but the forward projection encountering more resistance the projected whirls are afterwards thrown together, bifurcate and form outward and inward revolving whirlpools; the general directions of which are shown in the diagram, Fig. 148, on the last page.

d. The volume of the whirls about a vessel will be proportional, other conditions being equal, to the means of supply of water to them if this supply be effected by some less frictional mode of motion in the water than would be occasioned by a loss of amplitude by cramping the area of the whirls. In the case given 98 prop. *l*, the whirls are cramped by want of facility of supply, and the motion of the boat is proportionally resisted.

e. The mass of water in an entire whirl system moving about a boat at a given velocity might possibly be approximately measured by the momentum it gives to the boat above its mass into the resistance offered by the inertia of the mass of water it encounters when the boat is stopped by any means. This would possibly be as the volume of Mr. J. Scott Russell's wave of translation, described 34 prop. *d*, plus, the adhesion of the water to the sides of the boat. The same might be ascertained possibly by a boat moving forward at a given rate, urged by a propelling force, the motive value of which is known, the propelling force being reversed, until the vessel comes to rest in a certain distance; we may imagine that in this distance, the directive influence of whirl force about it will be neutralized. Let the vessel move from rest this same distance, and ascertain the propelling force used in volumes of elastic force of steam, or otherwise, then the difference observed will be from the momentum of the whirls; the resistances of the inertia of the water overcome being approximately the same in both cases, as an equivalent motive system is induced in reversing, to that of starting.

101. PROPOSITION: *The whirls engendered in a fluid by conic projection of the forward and side parts of a moving solid are forces set in motion by the forward projection of the adherent fluid which are restored with equal force in the opposite direction in other surrounding parts of the fluid or upon the solid to bring the contiguous fluid system to equilibrium after the solid has passed.*

a. The principles of action and reaction suggested in this proposition are important in suggesting the best form of a vessel to diminish resistance of the water in which it moves; and for the consideration of forces exerted upon rudders by which steering direction is given to the vessel.

b. Applying this proposition for the consideration of the best forms of vessels, the circuit of projection of the whirls will be representable by force lines, which originally projected by the vessel, will by their circuitous motion, return again and impress like forces, or a part of them, in an opposite direction upon a backward part of the vessel, or these forces may be thrown in collision with opposing whirls behind the vessel, and exert no compensating forward directing force upon it to that used in their projection. It would appear for instance, that if the circuit of the side whirls projected by the head of a vessel had such directive force given to them that they could complete a circle nearly, so as to impress reflex whirl force directly upon the stern surface; these whirls might then upon return contact have motive direction capable of urging the vessel forward. It would also appear from this mode of motion that there is a possible angle or curve for the stern of a vessel in which such whirls would meet the surface most directly to the forward motion of the vessel. On the other hand, if the whirl is cramped or overflows the vessel, and does not meet the surface in a direction capable of propelling the vessel, it may then otherwise cause a dragging action by a general traction upon the water behind, which forms a part of the unit projection.

c. We may have inference when the right form of a vessel is attained when the whirls formed at the sides of a vessel have freedom to exert their forces on the lateral parts by reflex action, as the liquid surface will then be little disturbed from its level plane. The force of propulsion of the vessel being wholly used in the projection of the whirls that are necessary for the displacement of the bulk of the vessel to ensure rolling contact.

d. There is another point that I think very important, namely, the principle upon which the back whirls by reflex action act upon the rudder of a vessel. I definitely assert in this particular case that the back whirls *act*, because their action may be very clearly observed in the surface motions at the stern of any moving vessel; especially in cases where, in the construction of a vessel, the lines have been well considered with regard to velocity. These stern whirls, when the vessel is going at full speed, appear as large discs, before described, which follow close behind the vessel near the position where they are thrown off after a complete revolution in a constant whirling motion, induced by the lateral surface; the evidence of which is clearly observable in the track of the vessel long after it has passed, not only by the absolute circular surface motion engendered, but by the relatively less vertical surface motion of the track, the surface waves being levelled as it were by the induced horizontal motion of the whirls which retain their whirling motion for a long period.

e. In a very important paper by Professor O. Reynolds read before the British Association in 1875, in reports, page 141, "On the Steering of Screw Steamers," Professor Reynolds has discovered the effects of the rudder, in cases of stopping or reversing the engines, by direct experiments with models, which experiments are of the greatest possible practical value. In the cases offered by Professor Reynolds I am not aware of any cause being attributed to the effects observed, or whether these cases rest in the *terra incognita* of fluid motions generally. But it appears to me that they can very well be fully explained by the principles of whirl motions which in this particular case may be made visibly evident by careful observation of outward forms only, without reference to any theoretical consideration. I may first state the important practical conclusion drawn by Prof. Reynolds, which he states in the three following laws:—

" 1. That when the steamer is going ahead she will turn as if she were going ahead whether she has steerage way or not.

2. That when the screw is reversed the rudder will act as if the vessel were going astern although she may be moving ahead.

3. That the more rapidly the boat is moving in the opposite direction to that in which the screw is acting to drive it, the more

nearly will the two effects on the rudder neutralize each other, and the less powerful will be its action. It would be reasonable to suppose that a boat may move fast enough to overcome the effect of the reversal of the screw; but this was not the case with the models."

f. Taking these facts to be explained by principles shown in the action of stern whirls upon a vessel, we find that in the first place, when a vessel is moving straight ahead the stern whirls are compact complete systems of motion, entirely motive in one direction about their centres, one large whirl being located near each side of the stern of the vessel. Therefore to move such a whirl it would require a force sufficient for its complete displacement that would displace an equal volume of the water. Further, by the induced rotary motion of the whirl if it were in any way pressed as by the flat side of the rudder, it would be constantly rotating upon the plane of pressure, and would act upon the surface of the rudder as an elastic body when compressed; the rotational force by tangential action producing the effect of elasticity. Therefore in the direct motion of the vessel the rudder when moved towards one side would be pressed by one stern whirl, and would by this pressure move the stern of the vessel by its local force and elasticity, to the opposite side where the whirl system by the direction of the rudder would be less active as a pressure.

g. Now if the vessel be stopped the whirls will be thrown forward and reversed. This stopping could not occur directly upon a vessel except in case of collision, but if the screw were reversed the flow of water in the tractional system of the whirl would project it towards the head of the vessel, and by this action the whirl would be thrown so far forward that it would not possibly be any longer active upon

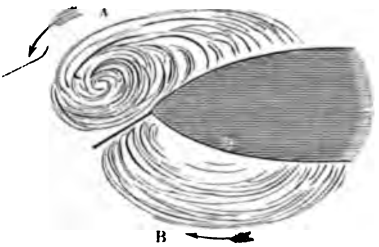


Fig. 149.—Ex.—Action of Lateral Whirls on Rudders.

the rudder. The general principles of these actions upon a rudder may be shown in the diagrams.

h. Fig. 149. Represents the vessel going at an equable rate, the rudder being turned perpendicular to the direct impulse of the whirl as shown on the lower side of the diagram at B, the directive force of this whirl will therefore press the vessel over. In this case the whirl represented at the lower part of the figure may be conceived to be completely displaced by its pressure upon the rudder. The freedom given to the whirl shown at A, in the upper part of the diagram, permits it to pass further astern. This whirl A may be thrown at such a distance astern that it may by its reflex curvature even assist the whirl B by its direct momentum in pressing the stern of the vessel over.

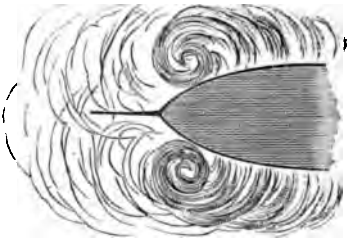


Fig. 150.—Ex.– Non-Action of Lateral Whirls on the Rudder when a Vessel is stopped.

i. Fig. 150. Represents the vessel when stopped, in which case the whirls are thrown forward. The same effect would be produced by the screw of a steamer being reversed; the whirls being now entirely inactive as a pressure upon the rudder.

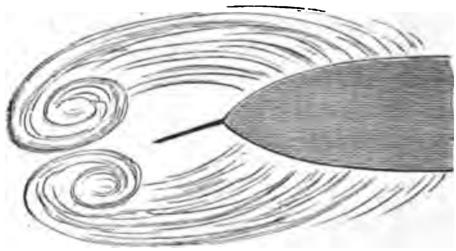


Fig. 151.—Diagram—High Speed the Rudder misses the Direct Impulse of the Lateral Whirls.

j. Fig. 151. Represents the case in which a sudden impulse is given to the vessel, the whirls are thrown backwards and miss direct impulse upon the rudder and the stern of the vessel, the line of forces still being directed towards the rudder, which would not receive much impulse from them. This is possibly an imaginary case, as such a high velocity as required cannot be attained; it is given in order to complete the system.

k. It is generally conceived, upon perfectly logical grounds, that upon gliding principles of fluid motion, the rudder simply directs the lateral stream lines from which it receives its impulse. If the rudder of a vessel were active in this manner, its proper place would be at the head of the vessel and not at the stern; but if the force on the rudder be derived from the pressure of the stern whirls, there will then be one general law, namely,—that the momentum of the moving liquid upon the rudder will depend entirely upon the direction and momentum of these whirls upon contact, such whirl direction being engendered from any cause.

Helical whirl deflections.

102. PROPOSITION: *That a floating solid moving horizontally in a liquid will deflect its friction whirls upwards in surface motions and produce waves. Such whirl motions by after deflections will become helical.*

a. In the several propositions in this chapter I have taken into consideration special directions of whirl motions about a projectile solid floating in a liquid, as being projected in a plane. I have followed the matter in this manner because demonstration was much more easy for a special case than for general complex principles; nevertheless, we must assume that from the nearly equal densities of water, for instance in every direction upwards, downwards, and laterally, that the resistances in all directions from the inertia of the fluid will not be materially different, and the same will hold for every divergence from the point of projection; therefore the whirl-generating force will be approximately equal throughout a *circular* area opposed to the projection in the liquid. This principle was fully discussed under conditions of fluid projection 68 prop., wherein it was shown that a whirl cut by a liquid surface would continue its perfect form beneath the surface until it was deflected upwards by the minus resistance of the aerial surface.

b. Although by the above conditions, the resistance to a floating solid, by the *inertia* of the resisting liquid, will be equal in all directions within the liquid, the mobility of the system will be very unequal, as the aerial surface will receive very little relative support by contiguous adhesion of heavy mass, compared to the deeper parts, and any form of induced motion once deflected to the surface or areas of less resistance will continue in this path of deflection; so that any open space that is necessary in the liquid for motions of accommodation for the friction whirls to be produced, must necessarily continue the projections into such space. In the projection of a floating solid body in a liquid that is adhesive to the solid we may assume as before that every point of adhesion will be resisted by a conic mass of the liquid at a certain angle forward of its direction of motion up to 90 degrees 58 prop. Now if we take one angle of resistance only, say that of 45 degrees, and assume the rigidity of the liquid such that it will resist the impulses of a flowing liquid at say one yard distance, then at every distance of one yard from the submerged part of the moving solid, at an angle included within 45 degrees of the forward direction of motion, there would exist an area of compression in the liquid.

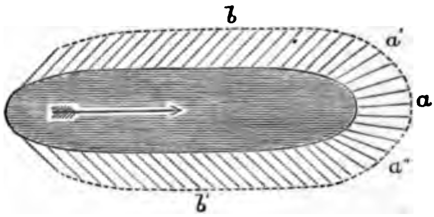


Fig. 152.—Diagram of Adhesive Projection about a Moving Body in a Liquid.

Let the equal lines surrounding the solid represented as in the model boat in the diagram, Fig. 152, be of one yard in length, then the conic resistance of the boat may be assumed to press back the liquid to this line, so that there will be an area of compression represented by the dotted line surrounding the boat in its horizontal plane at one yard distance, the resistances being assumed all equal, the surface water would be pressed back and elevated by the compression at this distance.

c. If we now take the vertical conditions of resistance by the pressures engendered in the motion of the boat, on the same principles as just discussed, then by the same arguments it will follow that at a certain line below the water as represented by BB′, Fig. 153, it may be assumed that all resistances will equally take direction of 45 degrees as *one* angle of resistance.

Let A A′ represent the surface of the water, B B′ a line below the surface, and C C′ a line at an equal distance deeper in the water. Now taking the same angle of 45 degrees as before, about this line

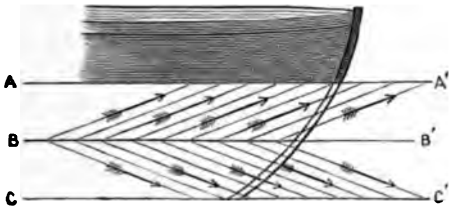


Fig. 153.—Diagram of Resistance about a Moving Vessel.

and the same lengths of radii; the pressing force from adhesion to the plane B B′ may be assumed to be upwards and downwards. In this case as all the points of pressure to the surface line A A′ would have no other resistance than from the air above, and all the points of resistance at the line C C′ would have the resistance of the water supported by continuity of lines to the land surface upon which the water rests, the axis of the lineal series of pressures represented by the plane B B′, by the minus resistance at the aerial surface, would then cause this plane to be deflected upwards to find equilibrium at some distance outwards from the adhesive surface of contact upon the boat; so that the deflection of the water caused by the projectile force of the boat, would thrust this plane of direction outwards, and throw it upwards towards the point A′ in the diagram.

d. If we now return to the diagram, Fig. 152, upon the plane, we find that the pressures at *a d′ a″* become pressures outwards and upwards by deflection of consecutive pressures that the boat meets. The pressures at *b b′* are pressed upwards but more outwards by the same forms of motion. Now in the above diagram the flowing force of the water meeting the projection about A will encounter the lineal resistances of the forward parts of the water, and there will be in this meeting part a hydrostatic pressure; the constancy of which will further press the elevated water to the most free part of the surface, which will be again outwards from the boat. By this cause a wave will be formed near the head of the boat directed outwards from it.

e. If we now consider the constancy of resistance by the opposing force of the liquid to the projection of the solid, on every point of the direct line we have taken to represent axes of cones of resistance, we shall find this line will be deflected to whirl forms; for instance, the lines of conic resistance directed to A′ in the previous diagram, Fig. 153, will decrease in force outwards and will by this means be curved over at this weak point by the action of the flowing force upon it; there will therefore be a deflection, to the form shown below, in front of the boat, and this deflection may even curl over at the highest point. Now, as the upward direction of motion will be by the hydrostatic pressures also outwards, by the constancy of resistance of radial forces, these forces will project the water by continuity of the resistance from the front, directly backwards and outwards, producing surface waves which will be by composition of these motions *helical* at the exposed edge, as shown complete in the sketch diagram, Fig. 155, below.

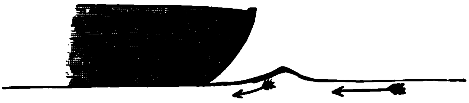


Fig. 154.—Ex.—Forward Projectile Wave.

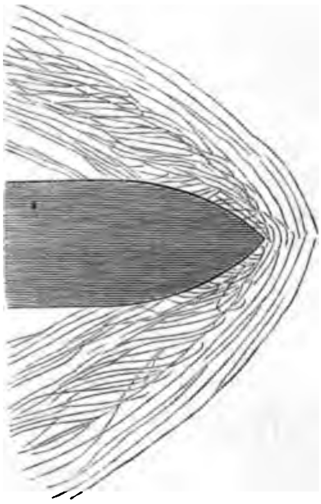


Fig. 155.—Ex.—Helical Deflection.

f. In this manner a complete *helical cylinder* will flow outwards from the bows of the vessel, and this will induce other following separate rotary systems, so that one outward flowing wave will generate another upon principles to be discussed further on. These helical motions will generally compound with the system of whirls discussed in previous propositions, so that the whirls themselves will be in most cases in a certain degree compounded of helical forms of projections.

103. Remarks.

I regret that my opportunities have not permitted me to follow this matter of free solids in infinite fluids to a further extent, especially as the subject appears to me to be full of useful results. I intended to take a voyage for observation of free liquid motions, but my bodily constitution is such that my mental energies are quite suspended on the liquid element, so that these investigations of practical results I must leave to others. I hope, however, that I have adduced sufficient principles by following previous propositions, to open a way which will show that the methods and formulæ generally devised for the resistance of solids by fluids, by some form of slipping motion of the surface water in contact, is probably erroneous. If the measurable adhesion of water were really to be entirely overcome, the value of which adhesion is shown in Mr. J. Scott Russell's experiment 95 article *d*, it appears to me, that available mechanical forces would be insufficient to move a floating vessel, at any rate, by such forces as could possibly be contained within the bulk of the vessel. But in a liquid system it is quite clear that principles of accommodation may occur, that may permit rolling contact of a not very frictional nature which will avoid the necessity of assuming slipping motions in any form.

CHAPTER IX.

DIFFUSION OF FLOWING FORCES IN FLUIDS. TERMINAL PROJECTIONS. RESISTANCE TO PROJECTION IN FLUIDS DURING DIFFUSIONAL MOTIONS.

Diffusion by interference.

104. *Diffusion of fluids in like fluids—general principles.*

a. The principles discussed in the fourth and seventh chapters, with the experimental evidence given, assure us that a flowing fluid will dissipate its energy upon lateral resistances, maintaining the central axis of projection at the highest velocity. We further have evidence that by the necessity of rolling contact, if we accept the principles offered in previous propositions, there will be division or intermittent action, deflecting the direct energy of the flowing current at its planes of contact, either with solids or with relatively quiescent parts of the fluid, into whirls or looped systems. These deflected parts have been shown to produce a retrograde motion in the lateral parts lineal of the current, and such retrograde motion we may imagine, reacting in like manner to ensure rolling contact, would produce again a retrograde action in lateral parts to its new direction which would tend to restore the current to its former direction. So that there is a possibility of deflection and re-deflection by which currents may be flowing in contact in opposite directions in lineal sections, their motive forces being nevertheless derived from one direct projection. We have further evidence that by lateral resistances, whirl systems will be developed to the greatest extent in the most free areas. Where such areas are large the circumferential parts of the whirls may be practically considered as direct flowing forces, and thus meet all the active conditions of direct currents, and as such, divide by tangential contact into separate whirl systems, thereby ensuring continuity of rolling contact. So that lateral resistances in open areas become sources of separation or of diffusion of direct flowing forces.

b. Upon the above conditions also, direct head resistances will cause bifurcation of central forces in every radial plane from the axis of the current, and the deflected parts will again bifurcate in proportion as they may again act as direct forces.

c. If direct projection of a fluid be made within a like perfectly quiescent homogeneous fluid, the whirl system induced remains very complete, but if there be interference or other direction of motion in parts of the fluid, the result is generally a diffusion of forces in which the projectile fluid is *split* up into many whirl systems. These general conditions I will now separately consider.

Lateral Diffusion of Whirl Systems.

105. PROPOSITION: *Every part of a fluid in rotation will have a tendency to throw off its circumferential parts into the open surrounding fluid; these rotary parts being withheld by the cohesion of the motive system only. Thus a whirl in an open fluid will separate at its circumference, and engender like, although smaller, whirls by parts thrown off tangentially. These deflected parts will afterwards move in the reverse direction to the original whirl by rolling contact upon the surrounding fluid, and the reversed parts may again divide by like tangential action, constantly, until the flowing force is entirely diffused.*

a. The most perfect self-contained whirl system will be that projected by a single impulse, in which case, a projectile whirl-ring will be formed, the involution of which will maintain the circumferential parts very compactly (67 prop. *d*, page 197). It is nevertheless evident that the exterior circumference of such a system, except in so far as the cohesion of the fluid withholds its matter, must encounter conic resistance in every free space of the same kind as that shown in many cases, as in instances given in 82 prop. *d*, page 231. So that if we do not imagine the cohesion of the fluid projectile system to be very great, the circumference of a rotary whirl of such a system will be constantly disintegrated into smaller whirls, that will be split off, as it were, from the circumferences of the larger ones in all more free or less resistant spaces; forming thereby surrounding circulatory systems; and these whirls will again be split into smaller still, if the resisting fluid space be open. This will also be the necessary form of motion to ensure universal rolling

e surrounding fluid by principles of whirl or biwh
his principle was discussed as being evident in *th*
contact whirls 82 prop. *c* for irregular spaces, and
ely at the edges of the section of a conoid 84 prop. *f*
also for the condition of jets and currents in the last

pproximate conditions to the above I have often
he rising tide of the Thames, in the inflowing water
gh the arches of London Bridge, where the current
by the piers of the bridge, which cause it to issue with
projectile force tangentially to the quiescent water
iers, upon the side of the bridge that is protected by
om the force of the direct stream. Here the current
the quiescent lateral waters, engenders a complete
ndreds of little whirlpools and still smaller whirl
ch are each the centre of a complete whirl whose
extends in depth to the bottom of the stream as a cut
prop., page 224). This complex whirl system spreads
d yards or so beyond the piers, each whirl forming
depression upon the water surface, the general super-
nce of which I endeavoured to delineate on the spot
tion of which the figure below is a reproduction.

continuity of tangential rotary action upon the quiescent waters where the tangential force is insufficient to form *whirl dimples* or *whirl discs,* shown in the evidence of a general horizontal rotary motion, whose visible effect is to make the rippled surface of the water more calm for several hundred yards down the stream.

d. In flat wide coast lines of shallow water, at the entrances of rivers into the sea, the vertical surface motions in whirls cause waves or ripples present gradually to disappear, and there is left generally a system of horizontal bifurcation and general horizontal rotation, visible by the presence of whirl discs, caused by the tangential action of the current.

e. The results of this horizontal diffusion of flowing force being in this case, as in all other observable like cases, that the surface of the water is calmed by the horizontal action of the whirls, so that the wind has much less influence to cause ripples or waves upon the surface than it would have even upon still water. This exactly resembles the conditions before pointed out, that occur after the passing of a steam-vessel over a wavy sea, wherein horizontal whirl motions are necessarily induced which subsequently move by tangential division, so as to leave a broad less wavy path in the ocean visible often for many miles.

Capital Diffusion.

106. PROPOSITION: *That a projectile, or a flowing force forming the head of a current before the continuity of projection can rotate a large volume of the resistant fluid laterally, will divide its direct current by constant bifurcation, until the projectile force becomes in equilibrium with the forward resistance.*

a. The conditions proposed, under which direct flowing fluids will bifurcate or become deflected by head or conic resistances, so that the deflected force can react after separation tangentially upon the surrounding fluid as a direct projection, and in like manner again divide upon forward resistance, is a process by which there appears to be brought about a constant diffusion of projectile forces in separate units of fluids acting upon themselves; this form of motion being special to fluid matter. The same motive principles will also offer the smallest conceivable friction to the first impulse of direct projection in extensive areas of resistant fluid matter. It is therefore possibly the manner in which diffusion of forces in fluids is at first mostly brought about, whether for such large masses as I have

prop. *d*, page 129 or for the smallest visible parts
r the ultimate division in molecular systems before
s are induced by projections through the resisting

bserved by evidence of experiment, that the biwhirl
wing force would permit continuity of motion in a
e constant force was so small as to be imperceptible.
a weak ammoniacal solution of carmine, the specific
ch did not exceed that of water at the same tempera-
$_{00}$ part of its volume. This, when placed gently upon
er, entirely floated at first, but gradually small pro-
es were projected by solution. These nipples possess-
ry small plus momentum, due to excess of gravita-
rojection into the liquid system, formed immediately
tems, and these again others, by constant action of
til they reached the bottom of the vessel or floated
n midway.

rrounding resistances in a fluid are constantly equal
o separate maintaining force as there is in the case of
ojections, just given, to exert its action constantly upon
ection from the central current, a simple whirl-ring or
n will be the only result; except for such lateral whirls

as resistances are encountered until exhaustion of the primitive impulse.

e. This tendency to constant bifurcation may be very well shown by an experiment of the projection of a very weak current, which we may follow by the same experimental means as before proposed, of rendering the resistance about a projection relatively greater by near adhesion of a liquid to a solid, through restriction of area, in reducing the projection to a thin section as follows:—

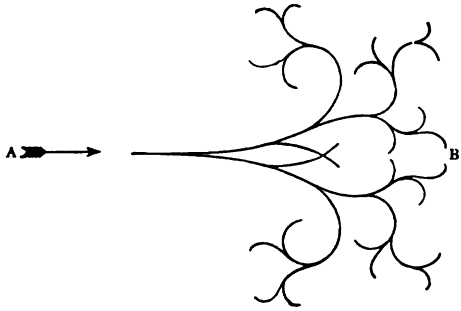


Fig. 157.—Diagram of Diffusion (theoretical).

f. Take two plates of perfectly clean glass, say of about six inches square, and firmly cement a border of card of about $\frac{1}{18}$ of an inch in thickness round three sides of one of the plates with marine glue. Then cement the second plate to the first. By this means a very thin waterproof trough will be formed, open at the top. If we now fill this with clean water and place it upright in a groove in a piece of stout wood, the experimental apparatus will be complete. To observe the desired effects, the trough should be placed before a window to transmit light through it, when the following phenomena of original fluid projection may be observed by the projected liquid diffusing itself by the constant force of gravitation under the resistance of the near surfaces of the glass. We shall need for the experiment in this case a fluid of much greater specific gravity than the carmine just mentioned, as the projection has to entirely overcome the friction of the surfaces of the glass. I have found ordinary black writing ink answer very well.

g. Take a pen full of ink and place this gently upon the surface of the water in the trough. The ink as it descends slowly by gravitation will be found to divide constantly upon the conic resist-

poses its direct projection, the divided parts having
mentum of projection to move the lateral fluid tan-
in cases discussed in the sixth chapter, to produce
extensive biwhirls. After the first division, the divided parts again divide, and these again, so that by this constant division and subdivision, the projected fluid takes a tree-like form. The annexed illustration, Fig. 158, was taken by transmitted light exactly following the outlines of the projection of ink in the thin trough described; it is therefore represented of the observed size.

ental
ns.

h. If we take the evidence of the above experimental demonstration of the diffusion of a fluid by weak constant projection, and under equal lateral resistances upon the conditions given, to represent a natural *law of diffusion*, we should then reasonably expect to find
be present as an influencing principle in the diffu-
orces in nature. Such, for instance, as we find pre-
on of liquids in the animal body, and the vegetable
rtain conditions, possibly more especially in the early

would be the least frictional for a constant flow through them afterwards.

i. Further, this diffusional experiment shows that a path of bifurcation is not necessarily a very frictional one for fluid matter, as it is shown evidently in this experiment to be the mode of projection least affected by the resistance of a uniform surrounding fluid to the direct action of a small gravitative impulse.

j. It is most probable that if the fluid systems of animal life were set out in homogeneous matter by principles here discussed, under certain conditions, this evidence would not always remain under the motive changes of animal life; but it might be anticipated to be evident in such parts of the animal tissue where there would be little strain by muscular action. In following observations as carefully as I was able, I found very generally some evidence of such a principle often or generally apparently differentiated by other causes. Thus as an instance, Fig. 159 is copied by the camera lucida upon the microscope from the injected arteries of the bladder of the shrew. The bladder, although muscular, is possibly in this case not under great or unequal strain after its first development. I omit in this illustration the finer divisions (capillaries) which continue in the like forms.

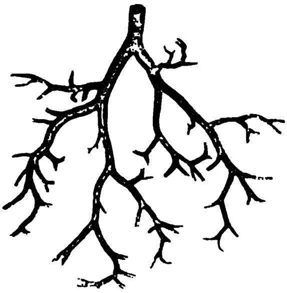


Fig. 159.—Arteries on the Bladder of a Shrew.

k. The same form is well developed in hepatic veins, which, possibly from the quiescent general state of the liver, from its absence of muscles is very little strained or differentiated by further development after generative formation. One complex system of which is shown in the engraving, Fig. 160. The same principle is also beautifully shown in the convoluted layer of the brain of which an illustration is given by Dr. W. B. Carpenter in his "*The Microscope and its Revelations*," Plate 25, Fig. 3.

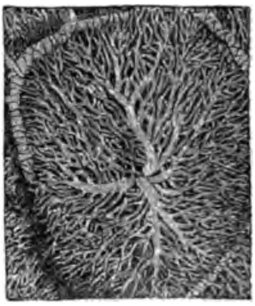


Fig. 160.—Hepatic Veins in the Human Liver.

l. It is on this principle we may possibly trace the true theory of the formation of tumours of the *sarcoma-*

ich often attain large dimensions, and contain a perfect
ystem entirely abnormal to the natural animal form.
inciples may also influence the development of mam-
ls. It is also possible upon this principle that animals
ulk by the plenitude of food supplies, by continuity of
elopment, particularly through the influence of inherit-
everal generations of similar growths. The vascular
small mammal as that of a mouse being but little finer,
an that of a large mammal as a deer.

bove theoretical deductions, it must be strictly observed
production of forms entailing constant bifurcation,
e a constant force in *one direction* in the system such
, or as the *influence of gravitation*, or there must be
arate cause, an inequality of density, or of resistance in
fluid or surface; for if the projection is final and the
fluid perfectly equal, a unit projection will produce a
ring only.

projection of weak currents.

OSITION: *That the lineal central area of a current by its*
ty will maintain its projection longer than any lateral
part. Therefore a terminal projection will produce an

the last proposition *g*, at the instant of time before the bifurcation of the extreme points of the divided currents. I have produced the same effects in solutions of gelatine, albumen, and other homogeneous resistant fluids. The illustration in Fig 161, A, is taken from the terminal projections in the same ink experiment as illustrated in Fig. 158.

d. That this terminal form shown at A in the annexed figure is an incipient whirl-ring system may be observed by further continuity of projection by the action of gravitation as in the experiment illustrated by Fig. 158. In this case the terminal whirl by further projection opens out to flat section into a biwhirl as shown in Fig. 161 at B, and by further continuity of the projection in the current, it again divides by the conic resistance; the separate whirls being connected by a stirrup-like neck as shown at C, which in continuity again forms incipient biwhirls as in the terminations shown at D, which are only a little more advanced than A. If the projection continue by gravitation, or a constant pressure in one direction, this subdivision is constantly developed as before Fig. 158.

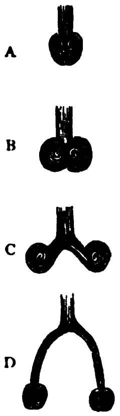


Fig. 161.—Terminal Biwhirls in Fluids.

e. If as suggested in the last proposition, nature avails herself also of this form of terminal fluid projection, such a form possibly will be permanently evident in the animal system. This appears to me to be in a certain degree the fact, although by the complex principles of vitality there may be considerable differentiation in the finally fixed forms, in such cases as this of sensitive equilibrium. It would possibly be therefore less evident in the blood-vessels, where in terminal projection in capillaries, the influence of the granular condition, as it were, produced in the blood by the presence of corpuscles, would destroy the perfect fluidity of the current, quite independently of the evident vital motivity of these corpuscles. But in nervous matter in fine nerves, there appears to be much greater homogeneity, and I find in the termination of some of the nerves the form here proposed of final fluid projection is fairly indicated, as in the Pacinian bodies forming the nerve endings of some of the lymphatics and some other cases. The same principles possibly hold in the formation of the Malpighian bodies in the kidneys; afterwards much differentiated. However this matter is so purely hypothetical that I will not follow it further.

e to projection of solids during diffusional mo-
ids.

OSITION: *That a fluid broken up into minute rotary sys-*
sional forces, will offer less resistance to the projection of a
thin it than when in a quiescent state of equilibrium.

position being purely theoretical, should be taken only
sense. The resistance in a fluid beyond the inertia of
s the momentum of the motive direction of its parts to
f any other body or part in contact with it.

cial conditions I offer for this proposition are that where
a body or a current has broken into a quiescent liquid,
ing whirl motions, the liquid will then offer less resist-
projection of the body or current for it to continue its
ion. It is assumed that in a current after it has broken
ant matter, in front of its projection, by inducing small
ms, that it will afterwards pass through the broken
with less resistance. This may be roughly conceived to
ain degree relative to the resistance to intrusion within
odies which admit of easy penetration after they are in
vision; for instance a plough impelled by a certain force
eadily through a soil of broken rocks that it could not
ocks were in their natural undisturbed condition.

ummer of 1876 I was much struck with the effects of dif except in a small degree close to the vessel. I have no doubt that the motion would have been less, had the water been shallower in Loch Ness, from the distance of resistance of the lower surface of the earth, so that the effect I have pointed out is only partly due to the causes shown.

d. The breaking up of the ocean surface into separate motions, which the system of each wave may possibly be, as I will hereafter discuss, will, upon the principles proposed, offer less resistance to the projection of a vessel than that which would exist in a perfect calm surface so far as the above principles are active; although it is most probable that the interference from directive wave motions to the production of a uniform connected whirl system which is assumed to be necessarily engendered about the vessel (97 prop.) to save friction of adhesion to the water, would more than compensate for any gain that might be derived from the disunion of connective fluid matter, particularly with so penetrating a solid as the sharp prow of a vessel. The difference of velocities of solids projected with equal power on smooth and on wavy seas might possibly decide this matter.

109. Remarks. Interference with Diffusional Systems.

a. In the diffusion of flowing forces, when these are active upon or against solid resistances, whirls will be established in all areas of greater repose, or of protection from the action of the general currents. The circulation of the fluid near such spaces of repose will establish systems of rolling contact for the less frictional continuity of motion of the projectile current. This principle was discussed, 50 prop. page 153, but in application to diffusional systems, many cases in nature become evident where there are present no bays or deep hollows as before considered, wherein we find that every surface irregularity appears to act with a certain directive and deflective force, to produce the minute diffusional forms now under consideration, near the surface.

b. Further, every solid projection of any kind from a surface opposing a part of a direct flowing fluid, however minute, will engender biwhirl action by the solid projection supporting a cone of impression, the principles of which have been discussed for larger systems in 39 and 75 props.

c. The activity of projections of solid matters in any form as interfering forces with the uniform resistances which cause equal

ty be observed in many cases by deflections about the
ions, by rotation of the fluid in the parts protected from
npulse of a current. Thus if an even stream of water
a vertical surface, every very small irregularity will
elatively large rounded protuberance or ripple, and the
e water will be covered with these protuberances which
foci of rotary systems that produce visible units of
contact of the water over the plane.

ace or shade necessary for the establishment of a rotary
be any area of surface that presents a hollow, smooth,
onal space, the unstable equilibrium of the flowing fluid
s to suffer deflection from very small resistance as I
with pipes in the seventh chapter. The like forms
engendered over every opening, pore, or even dis-
f surface, appears not only to induce rotary systems
s resistant space, but to influence the general motion,
ate division or vibration of the flowing system induc-
ty of like rotary systems, for a considerable area in the
l contiguous to these. I have traced this in musical
effects of openings. For the demonstration of a whirl
g established in hollows, openings, pores, and open
y mention a simple experiment I observed at an open
age window when the train was running, the air at the
very still. As I was sitting I constructed a small flag
out of my pocket-book by first cutting the leaf nearly
ts, leaving the part near the outward edges only, so that
moved freely as upon a joint; securing the one half by

entering at the backward part of the opening to the direction of motion of the carriage, and passing out at the forward part, which was much less defined in its direction, and of more expansive area, there being also evidence of intermittent action. Placing my flag in various parts of the carriage I found indications of perfect diffusion throughout the whole carriage; this was also rendered apparent by the particles of dust visible in the sunshine that entered the window.

e. The circulation of fluids in areas of repose is no doubt most important to vegetable life in bringing its food supply through the atmosphere, particularly in nearly still air, where whirl systems may be formed in every pore, more concave or more quiescent space, which the shaded parts of the leaf will secure for the faintest zephyr. The same principle will be active in hollow or curved spaces upon the leaf, where the apparent contractions caused by the ribs, form interspace hollows or relatively quiescent spots, wherein the air will be constantly circulating in whirl motions, bringing continual change of food supply from the passing current.

f. There is no doubt in my mind also, that numbers of interferences produce like shadings and divisions of direct flowing forces, or biwhirls, in the most shaded parts of the vegetable surface. Thus hairs, the serrated edges of leaves, and their pointed forms are such as will engender cones of resistance inducing whirl motions about the leaves, or the entire plant, and although the general principles of separate resistances, that cause diffusional motions, in the air may not be traceable to the functions of a single leaf, still the forms of plants may be such as to enable them to induce the circulation of the air necessary to bring food continually to their organs of reception. A field of grass may not in each blade receive the full value of its whirl-generating force to split up and divide the currents of air that pass over it; but upon the whole, it will be eminently adapted to establish such diffusional motions to attain this object by the number of points the blades of grass present.

g. There is nevertheless, I anticipate, some powers of engendering motive forces in the air in every plant for its own sustenance, as we find that a single tree grows much more vigorously if separated from others although there may be apparently the same conditions of soil and light, or even greater protection from injurious influences of cold dry winds. Further, we observe that every leaf and branch separates from others as far as possible; and trees will suffer almost

to reach clear air spaces, as we may commonly
ear the borders of woods.

also, that there is always present in the atmosphere
s of motion caused by unequal expansion of the air
The sun acting more directly on parts of the land
posed to his direct rays, as also more upon open than
; whereas radiation is greater or less according to
the local surface. By these means local currents
by the expanded air directing its impulses upon the
ces, causing thereby diffusional and intermittent
ly at all times ensuring a constant admixture of the
st important for the health of both animal and vege-

the above conditions will be those naturally induced
ere, there will nevertheless be a certain resistance t
ions, in the weak polar forces of the molecules o
, if we admit the presence of such, upon condition
first chapter. The influence of polar forces will b
tate of equilibrium of rest, so that such polar force
sional projections, that these projections will no
ers of constant forces but be produced and main-
ulses only. The condition of greatest polar tran-
that in which the molecules approach to neares
en masse, which will consequently be also the state o
y relatively to pressure, therefore a still atmospher
reatest density. In this possibly, we find part of th
ometer as a weather-glass; diffusion of vapour-bear

SECTION II.

DISCUSSION OF NATURAL PHENOMENA IN CONNECTION WITH PREVIOUS PROPOSITIONS.

CHAPTER X.

GENERAL CONDITIONS OF MOTIVE FORCES OBSERVABLE IN THE DIRECTIONS TAKEN BY NATURAL CURRENTS, PRODUCED BY HEAT, THE ROTATION OF THE GLOBE, AND GRAVITATION. REACTION OF NATURAL MOTIVE SYSTEMS.

110. General Conditions of Natural Systems of Fluid Motions on the Globe.

a. In offering propositions for the motion of projectile fluids, in the previous section, I have been compelled very generally to demonstrate principles as well as I was able by small table experiments, and in so doing, have constantly felt the necessity of reference to natural phenomena to give my ideas wider and more tangible elements of reality. This I have felt most important, to ensure the general applicability of the principles of fluid motion offered; as otherwise the motive effects, that I have discussed as principles, would possibly impress the mind as motions active in small close systems only. To obviate this defect in writing the previous section, I made at first, an attempt to give some illustrations by natural phenomena, but found that in proportion as I introduced such experimental evidence, to support my propositions, the natural phenomena themselves required for illustration so much general description, that the continuity of my ideas were obscured or lost, and the special principles of fluid motions I wished most particularly to impress, at the time, became complicated with other effects which represented only disturbing elements. I therefore determined, as I was unable to overcome the difficulty, that I would discuss such portable experiments only, as I was able to make, to

y ideas; and to set aside the consideration of more
ıtural phenomena for discussion in a separate section to
same, after I had considered the active principles that I
ere evident in the displacement of fluids generally; and
l therefore, I conceived, not depend in any way upon
ns of the motive systems considered.

ner inducement to follow this course of demonstration
in that, I could obtain considerable support from the
rections of general surface motions of fluids upon the
e observations of others; as also in some of the theor-
tions taken therefrom. This I found particularly the
liscussion of the general principles of air motion in the
by Sir John Herschel in his *Physical Geography and*
in the eighth edition of the *Encyclopedia Britannica.*
o general support for my propositions in the theory
circulation, of Lenz of St. Petersburg; which has met
ractical demonstrations in the valuable researches of Dr.
These matters appeared to me to lead to demonstra-
establishment of a system of aerial and oceanic circu-
was evidently active upon the same principles as those
ussed for other cases of projection and resistance in
ı by my small experiments.

These facts may also tend to establish a principle, I think exists, namely, that fluids *move* as perfectly homogeneous systems of matter in which impressed forces in unit masses act as the amplitudes and velocities of impression into the masses impressed, proportionally, whether the masses be the aqueous or aerial systems of a planet, or systems as small as those given in my experiments; or by *inference* in almost infinitely small systems, such as are possible in the circulation of the smallest animalculæ. In this matter I consider the smaller motions sufficiently demonstrated in the last section, so that I have now only the conditions of the larger natural systems to consider.

d. For the *generative sources* of motion in fluids upon the globe, which may act afterwards in the manner given by the demonstrations of my propositions, and which I wish to further assure, we have principally, the presence of ever-active forces of the sun's heat and the earth's rotation. The air and water volumes upon which these forces act remaining constant, and thermal forces cause local expansions, where the sun's rays fall most directly, thereby producing fluid displacements. We may anticipate in these displacements upon the surface of the globe, whose velocity in parts varies as the difference of circumference of rotation, that some general motive principles will be active in the direction of the fluids upon it, by which whirl systems will be formed upon every resistance to the direct impulse impressed. Such whirls or biwhirls being *free* or projectile if produced by *intermittent* impulses (67 prop.), or *located* in space, if, by the conditions present, the forces act with *constancy* (73, 77 props.); always assuming the fluids upon which such forces act to be in a state of equilibrium. In the operations of nature such freedom of quiescent equilibrium in the resistant fluid to meet the above conditions will not frequently be found, and we have then to consider such composition, or diffusion of forces, as may occur (109 remarks). Further, the conic resistance in one plane may meet with other forms of resistance which will deflect and *deform*, as it were, the equilibrium of forces in the entire system, as, for instance, the projectile central force of a flowing river will meet with very unequal resistances *vertically*, as above the central projection we have the air, and below the solid earth of the bed of the river, so that the equilibrium of resistance, by which equilateral biwhirls can be formed, will be possible in horizontal surface planes only, where equilibrium is produced by gravitation. And as regards *vertical motion*, whirls will l downwards only upon the resistance, as whirls of rolling urther, as the bounding aerial surface of water approaches n of a perfect plane, and that the land surface meets this where with nearly equal resistance *per linea;* horizontal will be always in approximate equilibrium, as regards ce motions, and, approximately, equilateral biwhirl sys- e found to be generally induced in this surface plane. On and, if a liquid or aerial system have considerable depth, re from any causes extensive under, over, or intermediate cupying broad bands of moving fluid, some cases of which fter discuss, such currents will form biwhirl systems, in *ion only,* in central parts, and generally to our powers of ance of such systems, will appear as continuous flowing g one uniform direction; so that in this case we shall ave surface motion quite distinct and often opposed to n of currents above or below certain gravitation planes.

es which move the fluids of the globe.

e convenient before entering into discussion of natural ns, to point out briefly the motive forces that act directly cal fluids; the principles of which in a general sense are nderstood by those who have studied the subject; this consideration of terrestrial heat derived from volcanoes and springs, which forms but a small element of heat-force in the great economy of nature, evident in superficial systems.

b. The radiation of heat from the sun has three distinct functions:—1. It acts directly to *expand* the air vapour and water, heating these bodies at the same time to a certain temperature, this expansion being greatest in the formation of vapour from water. 2. It acts indirectly by giving the heated bodies forces of radiation, from the temperature that they have received, which gives them again, *at another time*, an equal force of *contraction* or of condensation, which acts motively in the inverse direction to the original expansion, and with force equal to it, all bodies being assumed to radiate and receive heat according to Prevost's law of exchanges. 3. Heat acts also in producing currents, by rendering the expanded fluids *lighter*, and the radiated condensed fluids *heavier;* the parts of the fluid affected, seeking gravitation equilibrium, by the one part underflowing or overflowing the other.

c. By the important experiments of Joule we obtain knowledge of the values of heat expansions, as material forces, in the laws he has established for the equivalence of heat and mechanical force, in which we learn that every degree Fahrenheit of elevation of temperature of a pound of water equals the mechanical elevation of one pound weight to a height of 772 feet; and if we consider the known action of the sun in raising the temperature of fluids upon the earth, we at once have data for conceiving the immensity of the forces active in causing expansions; which will be at all times sufficient to account for the movement of masses of air and water, with the forces we witness, against the powerful resistances present on the earth's surface, and in the fluids themselves forward of the position to which they are moved.

d. The exact values given by Joule, if taken superficially, in relation to measurable inferences from cosmical phenomena, represent possibly only about one-third the absolute forces derived from heat communicated from the sun as ascertained in the manner that we are able to measure it by the thermometer; as the temperature of water, for instance, elevated one degree, has, during this elevation, exerted an expansive force, and performed the outward work of pressing fluid masses aside and upwards, as well as the intermolecular work of increasing palpable temperature. And the like work is again performed, after a certain period, by radiation and contraction heat, on another part of the earth, or at night, to bring ain to the initial temperature from which we at first aken; the heat-forces from surface waters being also ferred to the air and not lost. In the same manner the emperature in the ocean is observed to be only about Fahrenheit; but the quantities of heat-force utilized in of vapour over these regions is perhaps fourfold that ble by the thermometer. This vapour-force being made by forces witnessed principally in reaction, active else- nds, currents, and rainfall.

ect local influence of the sun upon separate regions of shown by Sir John Herschel,[1]—in that, "the same sun- at a vertical incidence, acts on a surface equal to its l area, when incident obliquely on the earth (including re), is spread over a surface larger in the inverse pro- dius to the sine of the obliquity. It needs little con- en, to perceive that at the poles, where the sun is below for half the year, and where during the other half it a greater altitude than 23½°, and *that* only for a short tive warming power on a given horizontal surface must inferior to that which it exercises in the equatorial re its meridional altitude never falls short of 66½°, and *g.* As the earth maintains upon the whole a mean constant temperature at all times, or as approximately so as we are able to measure it, it will be clear that the *earth's radiation* of heat-forces into space, from displaced fluids, is as great as its powers of receiving such forces by radiation from the sun. So that as the sun's heat-force diminishes towards the poles, whence fluids are directed by thermal expansions, the excess of the earth's radiational forces in these regions must be equal to the entire amount of heat thus received. And as the contraction of a natural body by loss of heat-force, in any manner, is inversely equal to the expansions per unit of heat-force; such contractions react locally upon surrounding parts with equal energy to the original heat expansions, as before stated.

h. By the obliquity of the sun's rays to the surface of the globe near the poles, we have here regions at all times covered with ice, therefore of constant condensation, whereas in the tropics we have regions of alternating expansion and contraction, or of *absorption* and *radiation* of heat, day and night, caused by the earth's rotation. We have, therefore, the heat expansions of fluids as directive forces, from the tropical area, *pulsatory*, and the polar forces of contraction, *constant.* The pulsatory action gives the fluids projected by heat-forces greater penetrating powers, upon principles discussed in the fifth and sixth chapters (73 prop. *c*).

i. The diurnal expansive effect of the sun's rays, upon the above principles must drive forward a wave of condensation, in both air and water, which traverses the fluid parts of the globe in its rotation, acting auxiliary to the tidal wave caused by the sun's attraction conjointly with that of the moon, these waves, being intermittent, are pulsatory in diurnal periods, and therefore locomotively projectile.

j. From the above it will be clearly conceived that we have established upon the globe, a thermal diurnal pulsatory force system, which expands fluids at the equator, causing them to flow or overflow outwards in the paths of least resistance, and near the poles, an area of constant terrestrial radiation of heat which acts as a condenser to bring over the expanded fluids; condensing and causing them to return towards the thermal equator, by their gravitation forces in their superior densities after condensation; by any path that offers at the time the least resistance to the establishment of equilibrium of the fluid systems as they rest upon the globe. Such thermal force under any conditions gives fluids upon the earth a general reciprocal action in northern and southern directions. The principles of action, evident in such motion in these fluids, resembles the circulation of water which we find in common practice in the heating of buildings by pipes, where the heat at one end of a system causes the constant projection of an upper surface current, whereas the cold or radiation of heat at the opposite end of the system constantly effects the supply of a denser underflowing one.

k. The warm air present at the formation of vapour, by direct action of the sun's rays and by reflection from the earth and ocean, rises with it, by the elastic forces of the expanded compound aerial fluid thus formed, to greater elevation under the pressure of lateral denser surrounding air, which is by this cause directed to underflow inwards beneath the lighter fluid from the nearest direction in which it can find a free or less resisted path to supply the loss. In this manner we have direct undercurrents projected towards the areas of thermal expansion and evaporation. To complete such a system, where the heat-force is practically constant, if taken for the whole globe, we have also necessarily a locality of condensation of vapour forces; otherwise such evaporation, if constant, would engender cumulative resistance equal to its elastic force by heat expansion. From this cause the condensed water in rainfall in temperate and polar regions produces inflows to partly equilibrate the excess of vapour-force active upon oceanic areas where the evaporation is in excess of precipitation.

l. Between the two areas of greatest expansion and contraction formed by the causes given above, we need the constant action of a system of reciprocally motive forces, embodied in the fluids acted upon, which in their movements seek the least frictional courses, that the accommodation permits to maintain a circulatory system, establishing means of supply in proportion to demand, to the aerial and aqueous thermal systems. These special local conditions I will consider further on.

113. Thermal Forces in Vapour Systems.

a. The formation of vapour as representing an expansile force, and of rainfall as a contractile one, are of such importance as elements of motive forces upon the globe, that this subject may with advantage be further considered for certain particulars.

b. First as regards the formation of vapour. We may possibly assume that the sun's rays, acting directly upon the aqueous surface, may be divided into two distinct functions. 1. A part of the sun's rays is evidently active upon the surface film producing *reflection.* This reflection may be conceived to be partly active in the form of heat and light, and partly in the molecular action of *evaporation;* possibly in the manner suggested in the 16 prop. 2. A part of the sun's heat enters a liquid by direct radiation, as other heat forces do in passing into, or through, transparent media. This radiation force of the sun's rays has been detected to be measurable by thermometers in clear water within a depth of 600 feet, as some experiments on board the *Challenger* show.

c. By the first condition offered above we have evaporation direct upon impact of the sun's rays, which, as regards the water evaporated upon the surface of the globe, may be considered to form an *intermittent* or diurnal vapour system. For the second, in which we have a general heating of this aqueous surface to a considerable depth, and in so far as the surface reacts afterwards by radiation, we have a *constant* evaporative force active at all times, day and night, which is particularly evident within intertropical regions, where it is found that the surface temperature of the ocean varies very little. This secondary constant force of evaporation is supported by the high specific heat of water, by which the heat-force is conserved with small outward elevation of temperature to react afterwards motively upon its reduction to lower temperature. There is also active, to support the constancy of surface heat, the presence of convection currents; which by interchanges, tend at all times to maintain the surface temperature as high as any part of the liquid mass.

d. Reserving a fuller consideration of the part that vapour plays upon the globe in special and local vertical circulation, and taking only general particulars, we may take it for granted that evaporation represents a constant expansile force over tropical areas by the formation of a *constantly renewed elastic fluid system,* which is intruded, and takes partially the place of the air. It will also follow that either at some part distant from or near to the tropics there will be an area of condensation where the vapour returns to water, its place in the aerial elastic system being only made up by ·001 of its original volume, which the water approximately represents in relation to its vapour.

e. Dalton found that evaporation forces rapidly decreased by loss of temperature in water. Thus a certain surface of water at boiling

evaporated 40 grains per minute, at 180° Fahr., 20
2°, 10 grains, and so on, until at about 39 degrees the
was very slow, although it continued at all temperatures
further experiments we infer that the tropical heat-
med in raising vapour are immensely greater than the
under greater obliquity of the sun's rays in the tem-
ns. Practically the air at the freezing temperature of
ree state contains very little vapour; so that we may
in all areas, condensation will take place to a certain
e lowering of the temperature of vapour, but that at
t this operation will almost practically cease, so that in
32° Fahr. we have generally to consider the effects of
s in producing contractions upon the air only, as before

continuity of the flow of air over water it will finally
rged with moisture from surface evaporation. This
invisible vapour, will be a conservation of heat-force
e partially restored upon after condensation. It will
ur in the projection of vapour currents that these may
into the polar regions, where the average cold would in
ort the vapour-force, were it not for the heat restored
ial condensation. Further, as we find that all polar
mal fluid forces possess eastern momentum relative to
velocity of the earth, by conditions to be discussed,
urrents as those of aqueous and aerial ones will thus
to easterly courses. It would also follow that at the
colder sides of these currents condensation would con-

condense proportionally by decrease of temperature. It becomes therefore probable that vaporous projections into polar areas fall generally somewhat short of purely aerial ones, so that assuming such vaporous forces to produce whirls, as I shall endeavour hereafter to show they do, by original thermal projection and condensation in separate regions, they would form such whirls of less amplitude than those formed by a purely aerial system. Some evidence of the above I will discuss further on.

114. Obliquity of the earth's axis in relation to heat-forces.

a. The obliquity of the earth's axis of revolution which causes our local summer and winter temperatures permits the sun to act in the expansions of the fluids presented, alternately, in the northern and southern hemispheres; the direct expansion over the summer half of the year being possibly about double those of the winter half. The intensity of the heat-forces increasing up to the summer solstice, and decreasing in like manner after this until the winter solstice, upon principles defined 112 art. *e.* The direct effects of the sun's heat-forces largely disappear in work exerted upon the mobile fluids of the earth. Thus, in the advancing summer the expansive force of the sun's heat only appears to increase the amount of cold in the temperate regions by acting upon the air and expanding it, a portion of the cold air being driven from the regions where the sun's rays now penetrate, against the resistance of the friction of its gravitation and adhesion to the earth. At the same time, the contractions of the air and water in the opposite polar area, by the radiation of the terrestrial heat attained in the previous summer, is drawing over and condensing the aerial and aqueous currents to equilibrate the missing elastic force derived from circum-polar surface radiation, which leaves the winter temperatures much higher than they would be if derived directly from the local effects of the sun's influence into the earth's radiation, particularly in early winter when the vapour condensations are greatest. From this cause, the sun's rays may even be absent for long periods, and yet the climate be quite bearable to humanity; thus in certain positions we find regions quite habitable within the arctic circle, where the cold would be intolerable were it not for the effects of this general principle.

b. The local motive values of heat-forces, modified by the obliquity of the earth's axis, may be partly shown by the winter and summer pressures over large continents where surface radiation is

Thus we find in the centre of Asia, as the researche
show, that the atmospheric pressure, evidently from th
condensation of the air, is on an average 30·4 in th
of January. Whereas, by summer expansions it is onl
ge 29·34 inches in July, or about equal to one inc
mercury pressure.[1]

the time of expansion by heat-forces over continental
the air is driven constantly to lower latitudes, and there-
ns of higher temperatures in the advance from winter to
se expansions represent immense forces; the increase
air at the same pressure being $\frac{1}{273}$ part for every degree
of additional heat. But this altogether forms only one
vapour forces are relatively greater in expansions and
ns, wherein the mass-reduction from vapour to water is
ousand-fold; such expansions and condensations aid
orming local winds.

over oceanic areas, by the difference in the obliquity of
ys, we have no similar directly measurable thermal
r loss of atmospheric weight shown by the barometer,
to that derived from the direct radiation of heat upon
causes expansion over continental areas; but in the
as the active vapour-forces as they are increased by
t must constantly increase also the amount of vapour,

as before stated. Such immeasurable forces being also largely derived from the latent heat absorbed in the one case, and released in the other, in the formation of water from vapour, and ice from water, and *vice versa*.

115. General effects of latitude velocities upon cosmic fluids.

a. There is no direct momentum of fluids at the poles relative to the earth's revolution, the earth turning upon an apparently immovable axis once in every twenty-four hours nearly; whereas at the equator the direct momentum is about one thousand miles per hour, the intermediate spaces being as the latitude velocities of the respective parts of the globe. By this we comprehend that by any transposition of a fluid north or south, the fluid will carry with it the velocity momentum of its mass from the latitude of the part of the globe from which it was displaced; which velocity momentum would be plus or minus that of the earth's velocity, according to whether it was directed north or south. The theory of this principle of motion was first pointed out by Hadley, *Phil. Tr.*, 1735, and was shown satisfactorily to give an eastern or western impulse to fluids relative to the earth's revolution, in all cases where these were expanded or otherwise directed northward or southward from any cause. The effects of revolution-velocity giving in most cases, particularly in nearing the tropics, greater direct momentum to the air, vapour, and water, than the direct effects of expansion and contraction, by the radiation of the sun and earth, in moving these fluids north and south by diurnal and seasonal expansions and contractions. Upon this principle the trade-winds are accounted for. There is one point in the effects of revolution velocity, in relation to thermal displacements, that I am not aware has been previously observed, which is important, namely—that the revolution of the globe being a circular motion around the poles of the earth; *that the influence of all thermal forces, which are direct or longitudinal motions to or from the poles, will engender elliptical orbits in displaced fluid matter.* These orbits may be complete or deflected by composition with other forces. This principle we shall find will materially affect the direction taken by aerial elastic fluids, but with water, the cohesion of its mass will resist motive ellipticity with a certain force; although the same influences will nevertheless be manifest in this also in degree.

s upon the globe cannot move constantly in one direc-
ction of heat and revolution forces without materially
avitative equilibrium, a fluid pressed to one part of the
m a resistance to following parts. In such resistances
m of projection will be largely conserved, for deflection
nto the path of least resistance, for the continuity of
vhirl motion being the general resultant; the whirl
irection in space, horizontally, vertically, or obliquely,
the composition of forces present.

v particularly the effects of the earth's revolution upon
urface, we may with advantage take the conditions of
case—and suppose for an instant the earth perfectly
space, that is, with no rotary motion, with its fluids
ently upon it, as formerly believed. If we now imagine
nly commences to rotate upon its axis, by movement
arts, in a west to eastern direction as actually. Then
ircumstances the inertia of the fluids resting near the
ld be able only *slowly*, from the mobility or infinite
eir systems, to take up the revolution velocity of the
; in fact they would resist movement as the entire
ir mass into the mobility of their systems. Under such
would be very clear that the equilibrium of the polar
not be greatly disturbed; but the inertia of the mobile
near the equator would throw them apparently, that is,
the earth's revolution, with great violence in a westerly
n this case the liquids would be powerfully projected
stern boundaries, or coasts, which they would overflow

minus velocity, so as to appear from the solid parts to be in motion in an opposite direction to that of the revolution, and that the waters, if resisted in such motion by solid parts of the globe would be deflected upon the resistance, and move under this deflection towards the polar parts where their velocities would be first brought to equilibrium with the rotation, and then by continuity of pressures causing further deflection, in excess of it; producing an apparent movement in an opposite direction. It would further be clear that such a system of drifting of the oceans upon their western boundaries, and of deflections to polar parts would materially disturb the equilibrium of gravitation by abstraction of water from the eastern equatorial parts; therefore gravitation being active proportionally to the elevation, the disturbance would cause the elevated waters to flow to equilibrium from the parts where the directive impulses were least active; and in this instance, the water deflected first to a western boundary, and then towards a polar area, would produce a return supply current to establish gravitative equilibrium along the eastern coasts, thus producing a complete surface rotation of the ocean.

e. If we now again return to the effects of a thermal force as discussed 112 art., assumed active on an aqueous system in projecting liquids on the globe to and from the equator, we may assume that every particle of liquid matter that may be moved as a supply current towards the equator will carry with it a minus revolution velocity, therefore it will be, in relation to the velocity of the latitude to which it is drifted, as *new matter*, which will be subject to the conditions considered above, of fluid *that commences to move* upon a rotatory globe, in the ratio of the minus rotational velocity that it will have in flowing towards the higher velocity near the equator.

f. We may now therefore confine our attention, for one condition of the motive principles discussed above, to a liquid *commencing to move* within a prescribed area, surrounded, or partly so, by resistances, which act to the liquid as a containing vessel, in preventing a general propagation of direct circumferential motions. We may take such containing vessel to be one of our great oceans, or any area of smaller dimensions, provided that the differences of velocity of parts of the system are sufficient to give a difference of momentum to the polar and equatorial sides of the fluid taken.

g. Under the conditions proposed above, experiment becomes much simplified, for we have in this case, instead of assuming a number of conflicting motions to represent the directions of surface forces, the condition of a fluid *at rest which commences to move.* We have at the same time demonstration in natural phenomena in the certainty of the inertia of fluids reacting near the equator, as we find in the direction of the trade-winds and surface oceanic drift, which transports the fluids themselves, and that must act, in regard to rotational velocities, as *new matter* which has not acquired the latitude velocity of the place whence it is transported.

h. If we now take the case of a liquid at rest in a containing area of resistance, for which conditions we may assume that of the Southern Atlantic Ocean; this area being convenient as it is included in moderately parallel meridional planes of resistance on two sides by the coasts of S. America and Africa. Then assuming that thermal forces direct the oceanic waters south from the equator, as just proposed, and that these waters in their new position now act as new matter which has not attained the minus latitude momentum of its displaced position. We may then represent the conditions I propose experimentally as follows:—

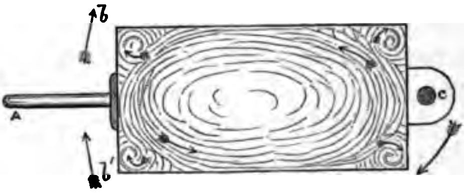


Fig. 162.—Ex.—Circulation by Rotation.

The trough shown in the engraving, Fig. 162, was made for trying this experiment; its dimensions were 30 inches in length, 20 inches in width, and 6 inches in depth. It was constructed so that it could be moved round upon a centre *c*. This centre may be assumed to represent the position of the terrestrial axis at the South Pole, in the illustration taken of the Southern Atlantic, when the apparatus is moved round by a handle fixed at A in the direction of the arrows *bb'*. For convenience of experiment the centre of the apparatus was supported upon a post of about a yard in height; motion being given to the vessel by taking the handle in the hand and walking around. The water flowed in the direction shown by the arrows inside the trough, which was made visible by particles of sawdust floating upon the surface.

i. On continuing to walk around, after a certain time, the water ceased to rotate, the friction of the vessel finally retarding it, and all parts acquiring an initial radial velocity. But now a current projected in the direction from A towards the centre *c*, assumed to represent the thermal effects proposed (112 art.), by means of a supply pipe (not shown in the illustration), the rotation recommenced *de novo;* and the same took place from a like projection of water in the opposite direction, from near the centre. In all cases the difference of revolution velocity in the projected parts constituting the motive force according to the minus or plus velocity derived from the revolution.

j. In a system of fluid of large extent the momentum of revolution would support its continuity, and smaller efforts of the forces derived from equatorial or polar directed flowing matter, would act cumulatively upon the rotary system.

116. Influences of gravitation in density systems of fluids.

a. The action of heat upon water is exceptional, in increasing and decreasing its volume; its greatest density being at 4° C.; the entire range of oceanic temperatures from 4° to 43° C., increasing the volume of pure water by about $\frac{1}{108}$ part (·0092) at atmospheric pressure. From this there is some variation of which I have no data for sea water, the greatest density of which has been found to be about 3°·2 C. at atmospheric pressure. This temperature was reasonably assumed by Sir J. Herschel and others to be the lowest at the bottom of the ocean. The experiments in the voyage of the *Challenger* have shown lower temperatures to 0° C., so that if there are in these observations no instrumental errors, we must assume that the density of sea water increases with loss of heat under great pressure to the freezing-point of pure water; under any conditions the thermal forces in open water, by the density and mobility of this liquid, will produce thermal currents, which are also made evident by experiments to which I have already referred.

b. The density of quiescent air and vapour resting upon the globe is found to vary inversely as the compression it receives, that is, as the mass resting directly above any area according to Boyle's law; the force of gravitation decreasing also with the altitude. It has been computed that from these causes, by the average pressure at sea-level, half the entire mass of aerial matter resting upon the earth would be contained in an average stratum of about 3·4 miles

f there were a continuous ocean covering the entire area.
usion of the land surface above the oceanic level this
possibly contained in about 3·6 miles above the average
l as it exists; within this lower denser strata the expan-
tractile forces of radiation and conduction of heat, and
on and condensation, are most active.

ion of the sun in the diurnal revolution of the earth will,
use the air to expand and form vapour upon the side
upon which its rays fall, and this expanded, or lighter
eek gravitation equilibrium with any contiguous more
r heavier fluid. Now as the globe is covered partly by
partly by land of various inclinations, in some parts in
flats, and in other parts in mountainous districts, the
nd contractile forces which are actively represented in
winds, will suffer considerably more resistance to grav-
lse in passing over irregularities of hill and dale and
lined surface generally, than upon more level plains. The
nd least frictional planes being uniformly those of water,
larger systems of aerial forces moved by thermal and
mpulses will seek the most uniformly level or least fric-
s, which are the large open oceanic areas. Upon these
and proportionally to the general limits of freedom
sistance of land surface, there will be established the
nd densest currents of aerial matter, which carry their
o inland from the liquid surface upon which they move.

tion to the general air space. This particularly applies to the special movements of the lower active carrying stratum. In this manner every point of land upon which a wind is directed from the sea is a powerful supporter of a cone of impression.

f. We may further conceive upon the above principles, that the lower stratum of air will also have a constant tendency, from its superior density to that above, to *continue horizontal impressions* of force engendered at the *oceanic level*, at this *level only*, unless moved upwards or deflected by some other exterior force which changes its gravitation plane of motion, such as the inclination of land surface, or the elastic reaction of compressed air in front of a directly resisted current.

117. Effects of evaporation and rainfall as gravitation systems.

a. The great heat of the sun's rays falling vertically over equatorial regions causing continual evaporation of the water surface, would if the water were static, constantly lower its surface over these regions; but as the fluidity of the aqueous system is such, that equal gravitation surface is possibly very nearly maintained, the abstraction by evaporation must engender a certain constant force of locomotion of the liquid mass towards the areas of evaporation, to supply the loss it occasions. The evaporation over tropical areas being constant, the air above such areas can be capable of maintaining only a certain amount of vapour at the temperature it possesses, at any time, until perfect saturation. It would therefore follow that the vapour must be projected indefinitely upwards to occupy space *per se*, or that it must fall as rain; but as there are always cooler areas contiguous to the regions of most intense evaporation, and that there are alternations of the most intense evaporation periods from day to day, and of relative cessation from night to night, we find that by the constant action of gravitation, contra to any possibility of unlimited upward projection, that a large portion of the water evaporated falls as rain upon the same or contiguous parts where there is only very slightly less heat force to maintain this vapour tension.

b. Under these conditions rainfall as superimposed liquid on the ocean represents at the instant of its fall a small directive force which aids the general direction of forces of expansion by heat, to overflow from the tropical area. This particularly occurs from the rain

here were a continuous ocean covering the entire area.
on of the land surface above the oceanic level this
ssibly contained in about 3·6 miles above the average
s it exists; within this lower denser strata the expan-
ctile forces of radiation and conduction of heat, and
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f. We may further conceive upon the above principles, that the lower stratum of air will also have a constant tendency, from its superior density to that above, to *continue horizontal impressions* of force engendered at the *oceanic level,* at this *level only,* unless moved upwards or deflected by some other exterior force which changes its gravitation plane of motion, such as the inclination of land surface, or the elastic reaction of compressed air in front of a directly resisted current.

117. Effects of evaporation and rainfall as gravitation systems.

a. The great heat of the sun's rays falling vertically over equatorial regions causing continual evaporation of the water surface, would if the water were static, constantly lower its surface over these regions; but as the fluidity of the aqueous system is such, that equal gravitation surface is possibly very nearly maintained, the abstraction by evaporation must engender a certain constant force of locomotion of the liquid mass towards the areas of evaporation, to supply the loss it occasions. The evaporation over tropical areas being constant, the air above such areas can be capable of maintaining only a certain amount of vapour at the temperature it possesses, at any time, until perfect saturation. It would therefore follow that the vapour must be projected indefinitely upwards to occupy space *per se,* or that it must fall as rain; but as there are always cooler areas contiguous to the regions of most intense evaporation, and that there are alternations of the most intense evaporation periods from day to day, and of relative cessation from night to night, we find that by the constant action of gravitation, contra to any possibility of unlimited upward projection, that a large portion of the water evaporated falls as rain upon the same or contiguous parts where there is only very slightly less heat force to maintain this vapour tension.

b. Under these conditions rainfall as superimposed liquid on the ocean represents at the instant of its fall a small directive force which aids the general direction of forces of expansion by heat, to overflow from the tropical area. This particularly occurs from the rain

and from its lacking salts, being thereby a lighter
of the oceanic surface upon which it falls. The rain-
reas, reaching the ocean by rivers and streams flow-
rial oceans, represents also, by difference of density,
jectile force. This is markedly the effect produced
of the Amazon and Mississippi rivers into the
tic system near the equator.

y of oceanic water as influencing gravitation

tions I have assumed for heat circulation are taken for
expanded in equal proportions for equal increments
ximately. In sea-water at atmospheric pressure the
y as before stated is said to be at about 3°·2 C., a
which open sea-water never appears to descend, the
low arctic ice, which is possibly the lowest near the
nearly uniform at about 28°.
where evaporation is in excess of precipitation, as, for
regions of the dry trade-winds, the salinity of the sea
reater at the surface; the evaporization being of pure
Such regions generally have a clear atmosphere, and
equator the sun's direct radiation has greater power

of changes of position of density strata, being possibly as the gravitation forces into the fluid resistances.

d. By experiments I find that heated salt water of *less density* than cold fresh, or less salt water will not remain upon the surface of the colder water, but the surface water will immediately lose part of its temperature upon contact with the colder water beneath and descend in convection currents, the surface heat being diffused with great rapidity. This experiment I have only tried roughly in a tall beaker of cold water coloured with ink, and hot salt water placed above it coloured with milk, wherein a diffusional system was at once established. By this experiment we may assume that where the oceanic surface becomes more salt from evaporation the heat forces present will be more quickly distributed, and produce an equable temperature to a greater depth. In this case the diffusion will only be limited in diffusional force by the difference of salinity falling off, when, by solution in the descent, the density of the saline part becomes nearly equal with the lower gravitation plane it reaches. We may assume from this reason, partly, (I will offer elsewhere more important conditions) that the range of surface temperature for a depth of about 1000 fathoms, nearly over the evaporating regions of the trade-winds, is higher than near the equator, where there is no excess of average salinity. The salinity in equatorial regions, where there is greater evaporation, being kept down possibly by the nearly constant diurnal rainfall. A greater depth of warm water at about 20° north and south latitude is observable in the section given by Dr. Carpenter of the Atlantic between the parallels of 38° N. and 38° S., page 11 of a paper read at the Royal Institution, March 20, 1874.

119. Reciprocal Action of Air and Water upon each other in Horizontal Movements.

a. Air and water as all experiments show are adhesive to each other. The entire average atmospheric pressure on any part of the globe represents an adhesive mass of about 2000 lbs. per square foot. Taking this as active upon a large surface of the ocean in its continuous movements, it may be considered to communicate its momentum to this surface by adhesion, so that we find actually in many cases, where the directive forces in the water are not very great, that the influence of the wind directs the surface flow; and this may be in opposition to the thermal effects of heat expanion contractions, upon the aqueous surface system, onsidered. On the other hand, aqueous projections g force upon the superimposed aerial fluid, so that erial fluids act reciprocally upon each other. We consider these conditions separately, although fluid y conserve their energies, so that the one force in times, enters into composition with the other.

e the entire momentum of the air in an extensive o be equal to about 32 feet of depth of surface water, as its superimposed weight at the surface of the nsider both systems of air and water as adhesive with no other resistance than the inertia of their if the moving air gives by a constant direction an water as its momentum value, that is, as its entire e water resists equally the momentum of the air, the ent of the liquid surface would be equal to half this; taken to move the surface water to this depth at locity for constant forces, or equal to half the depth water moved; this is entirely neglecting the mass e water. In this case it will be readily seen that nly be represented as a *surface force* in relation to rce in the entire oceanic system; the thermal force in natural aerial and aqueous systems of fluids:—In the aerial we can observe with exactness the lower surface, living, as we do, in this stratum; and in the liquid the upper, in living immediately above it. This must be in every way an advantage to us in arriving at a knowledge of the motive principles active in natural systems. It also greatly increases our powers of observing the separate conditions of fluids, both under restraint, as in the lower aerial surface, and of relative freedom, proportional to density, as at the surface of water; that is, assuming all fluids are comparable, and that they move upon like principles, irrespectively of density, of which I think my experiments leave no doubt.

e. In some cases, which are quite common in established cosmical currents, the contact of air and water in motion of terrestrial displacement is quite frictionless, from the equal velocities finally induced by reciprocal action of these fluids upon each other. This arises from the constant tendency of separate fluid forces to induce equality of motive velocity and direction at the plane of meeting of two fluids moving against each other. It is almost entirely from this cause that we observe in certain localities oceanic and aerial currents to be persistent in one direction by the constant action of forces in *one of the fluids*, some causes of which I have already discussed. This reciprocal action may occur in certain localities for longer or shorter periods. The aerial momentum, as that of the trade-winds, where directive forces are powerful and constant, may be assumed to act by cumulative efforts upon the aqueous surface, until the direction of the wind is induced in the aqueous surface. In all extensive oceanic currents, in like manner, where these are from any cause the superior or most constant forces, they carry onward the gravitating air resting upon them into their own directions, so that the great currents of air and water upon the earth are mostly nearly coincident in one direction. By the constancy of active impulses, derived from the same set of causes, certain systems of aerial currents become approximately fixed locally, over certain liquid areas. Such constant systems are not often found over land areas unless the projection of the aerial fluids can be clearly traced to the continuity of momentum of motions induced on oceanic areas; or that they are necessary as supply currents to replace local projections, as, for instance, the prevalence of south-westerly winds on certain western coasts of this country; these being even much less frequent at a short distance inland, than on the western coasts nerally, as a principle, the land surface being immobile, impulses of aerial momentum are here lost as cumulative epresent the effects of immediate causes only; whereas impulses of directive forces acting on a mobile system, ter, act cumulatively to its directive energy. We ther that for the higher strata of aerial motions, the aerial fluid may act as a mobile system to this, and in semble, as regards the friction of resistance, the action aerial system upon the oceanic area.

ion of the Subject to follow Natural Phenomena.

v be convenient to divide the subject to investigate the itions whereby we may be enabled to follow the reviously offered into natural phenomena. For this ll take

ntal Motions in Aqueous Systems.
ntal Motions in Aerial Systems.
l and Oblique Motions in Aqueous Systems.
l and Oblique Motions in Aerial Systems.

der in this chapter that I have sufficiently discussed the

CHAPTER XI.

HORIZONTAL WHIRL AND BIWHIRL SYSTEMS OF MOTION OBSERVABLE IN NATURAL PHENOMENA IN WATER:—OCEANIC AND FLUVIAL WHIRL SYSTEMS.

121. Projection of Rivers into the Ocean.

a. The outflow of a river upon entering an ocean or a lake may be taken as a very definite form of horizontal projection for a large mass of water subject to less interference than in open currents generally. It will therefore be convenient to consider this first. A river has commonly a transverse section of less depth than that which would form a complete half cylinder of projectile fluid. Hence any biwhirl produced by this projection would be formed upon principles given in 79 prop., where the section of a whirl is found constantly to be actively extending its radius. We can also imagine that by rolling contact of a stream upon its bed, the higher radii of motive forces in the central or in any deeper or more free parts of the current, will produce higher velocity in these parts, causing them thereby to act as effective projectile forces to the more quiescent or shallower spaces lateral to the current. In this manner the central part will possess the highest velocity where it enters an ocean or lake, and must therefore at this point encounter greater head or conic resistance than in the slower flowing lateral parts; so that the conditions will be such that an entire biwhirl motion will be a general resultant; the whirl system in this case flattening itself out, as it were, to meet the extent of free area opened out to it at the mouth of the river. It will also follow, that in the outflowing of a wide stream, the active tangential force upon the still lateral waters, within the ocean or lake, will have a constant tendency to set the quiescent water in horizontal revolution. But if

flow have considerable velocity, it will after a certain
direct force far into the ocean, making rolling con-
lateral whirls first formed; or if the area be free
istance, it will engender a more extensive biwhirl
e of impression upon the resistance of the static
only far forward. The lateral whirls so produced
extent, according to the volume and velocity of the
id and the quiescence of the lateral waters. They
ve, include all minor biwhirl systems engendered by
es, upon principles previously discussed for diffusion,
m whatever cause. Upon these principles a stream
the ocean will at all times represent a *biwhirl gener-*
hich will be highly developed if the stream possess
r great central velocity; the whirls being also exten-
stances are slight or distant, as in the projection of a
raight sloping coast in calm water.

ther observe that a biwhirl being a planic system of
project its force into the ocean with very little surface
composition of forces; its motive direction being hori-
also tend to calm the vertical motion of surface waves,
stinct means of indicating the extent of whirl action
d surface. But the most direct and certain means of

same principles as rivers entering the ocean, but are subject to more interference from compositions with cross currents, undercurrents, and winds.

122. Formation of Deltas at the Mouths of Rivers.

a. Upon the principles above discussed, as being active in biwhirl systems, at the entrance of a shallow river into the ocean, there will under the same conditions of conic resistance be formed forward an area of *quiescent compression*, upon the resistance of the oceanic water, which will be of such an extent as to equilibrate the flowing force of the river; this being the condition shown in 73 prop. for a cone of resistance. Now, this being the case, every particle of solid matter brought down to the ocean by the river will have its velocity retarded at some forward point of resistance, and as a current is found to carry alluvial matter nearly proportional to its velocity, it will occur that at this point of retardation, portions of solid matter, that are only held in suspension by the motion of the water, will be deposited. It will be seen further, that deposition taking place by solid matter projected into the cone of resistance in an oceanic area that there becomes developed a conoid of impression of the rigid kind shown 65 prop., and as flowing forces are easily separated by resistance (75 prop.), a biwhirl opens over the resistance formed by the deposited tertiary matter in this conoid.

b. We may further conceive, that after a local biwhirl system is formed, every particle of dense solid matter brought down by the river and deflected into lateral whirl systems, will, by its superior specific gravity to the water, have also superior tangential force in the whirl into which it is projected; that is, its direct momentum will be greater than that of a less dense body, *per volume*, as a part of the flowing system. It will therefore occur with tertiary matter carried by the current that the heavier particles will be ejected towards the circumference of the whirl on all sides. Upon the same principles also, any lighter floating particles will be drawn inwards towards the centre of the whirl system.

c. It will be clearly seen from the above that the relative retardation of the flowing forces and consequently the greatest resistance is upon the vertex of the cone of resistance, which is placed where the stream possesses the highest velocity, carrying therefore by this velocity the largest amount of alluvial matter. As this vertex is is of deflection and that the flowing force conserves although resisted; this vertex becomes the starting lse that acts motive to the entire biwhirl system so efore by this cause the greatest amount of alluvial vn into the circumference of the whirl, or more par- the cone of resistance, where the retardation of direct conservation of elastic force takes place. In this relatively a quiescent space (70 prop. *e*), a delta will ily formed, which afterwards takes the place of a ression to the projected liquid.

entally I have found it very easy to form deltas, with ents of muddy water flowing upon shallow still water, es the same as those which hold in natural pheno-

o be apparent that as soon as a cone of resistance is uvial matter, the matter as it is deposited will react n the resistance of the cone. Further, as the action s to eject more solid matter by tangential force from nay, by the continuity of this action, form pools or laterally upon the underlying land surface, in which erwards rotate with less friction.

above principles, deltas will be formed by every shalconsequently its greatest velocity at the most exterior or eccentric free portion of the whirl system, that this exterior is also the plane of greatest resistance to the whirl. The induced velocity in the central part of the system constantly eliminates force into the external resistance; therefore a whirl once formed is also at its complete formation in a state of dissolution at its exterior surface, where the resistance is gradually reacting upon the projectile force. It thus occurs that a certain part of the tangential force in the whirl may, at any open point in its course, become a current in mobile lateral equilibrium, and in this state be split off from the whirl system having tangential force left direct, for this deflection into the open fluid. In this case it would in continuity of projection immediately meet again head resistance, liquid or solid, so that it would again bifurcate and form a new biwhirl system, upon principles similar to those discussed for diffusion in the ninth chapter, so that in any case of the entrance of a river into the ocean on an extensive plane of equal resistance, but not of great depth, there would be formed a *series of deltas*, or at least a series of biwhirl systems, which, if they contained tertiary matter, would develop into deltas.

h. If we apply the same principles of motion to larger systems of oceanic currents we may imagine these to be active in forming land areas, which by their pointed forms meeting the oceanic currents directly, will resemble deltas. In this manner the establishment of a powerful biwhirl system from any cause will leave a delta of rotative repose where whirl forces are inactive, although they will be most active about the outline of the delta (cone of resistance). I think it possible to this cause, and the general influences of whirl action that we owe the pointed forms of continents and islands which are directed very generally towards such currents proceeding from the more open oceanic areas, wherein directive impulses are most evident. The whirl action in these cases, tending by tangential force in the masses of oceanic waters projected, to wash away prominent coasts that are frictional to the whirl forces, and to deposit the matter detached in exterior areas to the whirl system, where the least interference occurs. Thus for instance, currents directed from the Southern Ocean would establish whirls upon any headland, and these whirls when established, as for instance in the S. Atlantic, Indian, and Pacific oceans with free oceanic areas for projection from the south, would have a certain tendency to conic pointing

nts of South America and Africa. In like manner,
currents directed northward by thermal causes in the
nd Bay of Bengal, open to the impulse of the Indian
tend to the conic pointing of India, and the same
so in Greenland to the Atlantic currents. And gen-
test oceanic area lying actually southward, the point-
enerally in this direction from the greater magnitude
orces; the motive heat forces, summer and winter,
re proposed, direct impulse. The obliquity of the
iving southern and northern momentum to currents by
would, also by the differences of rotational velocities
s of the earth, give directive influences to the current
ansions and contractions, and tend to place the con-
d to the currents, formed and directed from the open
pointing somewhat *westward*, as these westerly sides
ticularly the whirl forces. This matter I will endea-
e further in special cases; the present conditions refer
I do not claim for this principle more than an influenc-
could scarcely be assumed to affect the contour of an
of rocks except in a small degree; but if a surface
loose tertiary matter and rising in an oceanic current,
ght be influential in establishing the contour of such

which will be particularly evident where it passes over a short distance of flat country. In this case also, not very large impediments in the central area would support a cone of impression, and at this position the stream would have a strong tendency to bifurcate, the flowing force being thus deflected, so that a central island would be formed, on the same principle as the deltas before considered, if the banks at this point were not too resistant to restrain the whirl force of the biwhirl present at the point of resistance. On the other hand, as soon as the stream has separated about the island, the separate streams would again form biwhirl systems, whose tendency would be to meet again further down the stream by the minus resistance towards its former channel. The same principles will hold for the formation of an island in an oceanic current.

124. Conservancy of Water Courses.

a. By the above conditions it will be seen that a river flowing through a flat country will have a constant disposition to expand, and will not cut out for itself a central course unless there are present some local causes, geological or otherwise, to produce this effect, that is, as far as the whirl system of its motion directs its waters; this point has been already discussed 91 prop. But in this very same system we find a compensation, in that the higher central velocity directs lateral whirls, by which alluvial matter, upon principles just discussed, will be carried towards the banks by the force of the tangential projection of these whirls. Further, the borders of a stream being relatively quiescent, in proportion as the waters have less velocity, alluvial matter will deposit in lateral parts, and by this means conserve the central course open.

b. The conditions under which a current will be best conserved, upon my theory of whirl force is that in which its bed is of some cylindrical section not less than half cylindrical, except that there may be a small function in equation for gravitation of the water. This will appear to be the best section, by the conditions of the whirl ring cut in horizontal section, 68 prop., as the whirl system would then exist in equilibrium, the equal divergency of the water in the whirl from the central deflection impressing the same force at the bottom of the stream as at the sides. The current would therefore be eroded and have alluvial matter deposited equally, and be thereby maintained intact in its form.

c. If the section of a stream be shallower than a semicircle there ant tendency to divide or to deposit mud in the cen- tion of the current to one side or the other, where the attains greatest tangential force. This may be im- e engineering works in the economy of river embank- cylindrical streams may be formed of less area than conomy of construction, the best form being at the uired thereby, to keep a constant open bed with the n of resistance to the free gravitation-velocity of the he same manner unrestricted direct open currents of be also of semicylindrical section.

Principles of Biwhirl and Whirl Motions in ents in Superficial Areas, generally.

the most clear evidence of the direction taken by in fluids, the action of which, must be as all forces may be found in the great masses of water free from ance of solids contained in our oceans, the *eddies* be the whirls or biwhirls of the systems of fluid ed in this treatise. I have not used the term *eddy* as that of *vortex* motion previously discussed, has some- plied to other forms of motion than those I wish to me cases, where the mind could only recognize con-from any cause is directed towards a coast; in which case, the coast will so far resemble a delta that it will support a cone of impression, and deflect the flowing current to the right and left of its direct course by biwhirl action. Even in this case it may seldom occur actually, through indentation of coast or otherwise, that the current will strike the coast directly normal to its line, so that the cone of impression that may be formed possesses a base symmetrical to the current; but more generally there will be such variation by deflection from a right angle that the resistant water, in front of the coast, will produce an irregular biwhirl, in which one whirl will largely predominate over the other.

c. In oceanic currents moving by rolling contact where the water is deep, the friction of surface motion is very much less, perhaps nearly proportional to the depth, taken as a radius as before proposed, other conditions being equal; therefore in deep water and open oceanic space, larger areas of water are relatively free to form whirl systems by much smaller active impulses of tangential force in moving upon the inertia of lateral masses. Further, oceanic systems of motion, from the extent of the masses finally moved by cumulative efforts, and the momentum these masses afterwards carry, are very persistent in the continuity of any system of motion once induced. This principle applies either to motions of rotation or of translation in direct lines; such motion being subject to less local change, when smaller forces are impressed at intervals of time or locality; which enter cumulatively only, either as accelerating or disturbing influences, in the general composition of their forces of established movements, which these large masses of fluid at the time may possess.

d. If we now consider some of the great oceanic forces of the globe, we have in these, masses of many thousand miles of surface water of great depth, moving with velocities of twenty or more miles a day, the momentum of which it is almost impossible to measure. We may nevertheless take these currents to represent enormous flowing forces, which we may fairly follow into their deflections and observe the effect produced on the inertia of the more quiescent systems of water, of equal or greater mass, placed contiguous to them. We may take for one instance of a mighty current, the united western equatorial drift over the North and South Atlantic as a case of the projection of fluid force on a very large scale, the origin of which is derived from thermal and

es discussed. This current may be conceived to be
e combined impulses impressed by aerial and aqueous
ogether cause the projection of a liquid mass that
reater part of a broad belt, very definable in the
Southern Atlantic Oceans, extending generally over
es of latitude, of which the thermal equator in about
the central line. These large currents meet only
n limit, leaving a medial band of about 5 degrees
countercurrents, the cause of which will be here-
d. This entire united equatorial current in both
southern hemispheres, although it varies slightly at
ns, we may consider as a constant projection of fluid
ttains an approximately equal velocity in equal
a large part of the extensive areas taken. We
e Pacific Ocean a similar projectile system derived
set of causes.

ng into consideration the direct momentum of the
currents, upon principles discussed in the proposi-
atise, we witness in these equatorial surface motions,
ng forces moving tangentially to extensive free
of deep water; the effects of which, upon the prin-
motions discussed, is to engender rotary systems,

126. Whirl System of the Southern Atlantic Ocean.

a. Perhaps the best conditions for the development of a complete oceanic whirl, of extensive dimensions, occur in the immense bay, if I may so term it, of the Southern Atlantic Ocean, which was before taken for demonstration of rotational movements, 115 art. *h.* Here, between the coasts of Africa and South America, the inflowing southern equatorial current is deflected and directed at its outset by the influence of the equatorial parallel of land reaching along the coast of Africa from Fernando Po to Cape Palmas, where, were it not for the resistance at the equator, caused by the directive action of thermal forces, the aqueous force in whirl circulation would take a circuit onward to this coast and throw the equatorial current in one broad equatorial band direct upon the immense headland on the South American coast, of which Cape St. Roque forms the forward point of resistance. This is possibly the direction taken by the undercurrent, or denser system, which derives its force largely from the impulse of the open Southern Ocean, to be hereafter discussed. The surface equatorial current, which follows directly the thermal effects in this region, keeps near to the equator, moving from east to west, possibly uniting the surface currents with the underflowing whirl proposed, so that the entire system projects its direct momentum upon the same cape of St. Roque. The united current is here split against the cone of resistance that forms in the static water in front of the cape, and by the cumulative compression of the elastic force developed by the resistance, divides the current, three hundred miles before it reaches this headland of St. Roque, 40 prop. *d.* The coast supporting a cone of impression, as in the case shown 77 prop. *c*, causes a general bifurcation of the Atlantic equatorial current at this cape, which deflects the direct force of the current north and south. The northern deflection flowing along the north-eastern coast of South America forming the Guiana coast current, and the southern flowing along the coast of Brazil, forming the Brazil current.

b. If we take the southern equatorial current as it exists at a position of great motive activity, say where it crosses the meridians from 10° to 20° west; it here forms a band of nearly 500 geographical miles of average width. If we consider this as a motive liquid moving at about 20 miles per day, directed by its westward drift upon Cape St. Roque, it would be clear that such an immense stream could not be brought entirely against this cape, or upon any

sion we may imagine, directly in front of it. It must
principles discussed, have the central portion of the
ed over such a conoid of impression in a manner that
vaters themselves may form the head resistance to
lowing parts. In this manner the directive momen-
rent by the smallness of divergence from direct im-
nakes upon the covering of the cone of impression,
press it, will react cumulatively upon its velocity, by
ateral compression; so that the deflected current in
th these forces will have its velocity increased there-
tion, upon the same conditions as those discussed for
of a pier of a bridge in a running stream, 39 prop.
urrent we find, that the velocity is most increased
ern side, from causes to be hereafter discussed. The
ntic equatorial current as it appears in the excellent
f the world by Herman Berghaus of Gotha, which I
in these researches, after bifurcating in the ocean
St. Roque, takes a grand whirl over forty degrees of
he same of longitude with a small deflection only at
ood Hope, returning to complete the whirl by the
back into the equatorial current from which we at

whose vertex is the small island Fernando Noronha which forms a part of a natural delta to this current. Then the largest area for this southern whirl, upon principles discussed 82 prop., will be that of the greatest circle of equal resistance. This upon a map of the South Atlantic may be found to have its centre in about lat. 20° S., long. 14° W., but from deflection caused by the great width of the equatorial current, the centre of inertia of the waters of this ocean is probably about 3½° further south, or exactly upon the tropic of Capricorn; and by the principles of its projection, if we were to stand at this point, which should be one of constant calm as far as oceanic movement is concerned, then by causes now given, the water should be moving in every direction tangentially to our central position from right to left. The entire rotation of this absolute area being nevertheless extremely slow near this central position.

f. Although the above may fairly represent the absolute conditions, we must not lose sight of the fact that the resistances about the circumference of such a gigantic whirl as here imagined are not equal. Thus if we describe a circle upon a globe from the position given above in lat. 23½° S., long. 14° W., for a centre and with a radius to scale of about 1200 geographical miles we shall be fairly in the current for the entire northern half of the circumference; as the resistances from the southern coast of America from Pernambuco to Rio de Janeiro will be nearly equal, and the coast of Africa from Ichabo back into the equatorial current also. The equatorial current being assumed the motive force will form of itself a resistance on the northern side, as in cases given 81 prop. The resistance will also be nearly equal upon the cone of impression about St. Roque, therefore this part of the circumference of the whirl will be fairly made out by surrounding nearly equal resistances. When the whirl current reaches Rio de Janeiro there is no cause for its discontinuity as a revolution of a conoid of persistion (79 prop.), except that we have here an area of less lateral resistance from the greater distance of land upon the southern side. Therefore a large portion of the tangential whirl force is released at this point, and thrown into the Southern Ocean where the resistance to its impulse deflects part of its volume, as before stated, further southwards along the coast of South America, and another part continues by liquid cohesion in the induced rotary system of the great whirl described; so that this whirl, although weakened, is complete for another fourth part

ɔr back to long. 14° W. Here the diminished force
ʋeakened whirl current is approaching the coast of
it meets again an open area to the circumference of
elation to the distance from the centre proposed, in
ape of Good Hope, upon the African coast, which
ıpport for another cone of impression, so that again
angential force is split off, and only a vestige of the
ɔrial projection continues in the whirl system of the
ı of the South Atlantic whirl; this part is, however,
ngthened by other causes yet to be considered.

principles discussed the area taken of the Southern
form a kind of basin surrounded by currents which
rying forces, but would all flow from the position of
n right to left. There would therefore be in the
f this immense basin a mass of water that would
hafed by the tangential forces of the circumscribing
ı by the natural cohesion of the liquid system must
ıg the entire mass into revolution upon its centre of
ɔ prop., or in some way break off connection with it
ɔrders of the central mass of the system. Further,
t resistances to the tangential force of the moving
constantly on the circumference of the whirl, although

and more exactly than elsewhere. In this immense area also, by the irregularities of the bounding surfaces, there are generally interferences with the establishment of simple whirl systems, which lead us to consider principles of projections which are very generally active in other cases.

b. In the North Atlantic Ocean, by the form and position of the land of the north-eastern coast of South America, as before stated, a large part of the southern equatorial current of surface force is deflected into the Northern Atlantic oceanic area as shown by Sir John Herschel. This is probably necessarily so as the southern area is more aqueous and thereby a more free system to maintain impressed force. The northward deflections of these united surface currents is no doubt correctly conceived to be one cause of the higher temperature of the northern hemisphere, particularly where the directions of whirl and tangential forces throw a large part of the surface water upon Western Europe. This communication from South to North Atlantic produces a *longitudinal* aqueous motive system extending from pole to pole by which certain influences of the S. Atlantic Ocean enter materially into the northern system; aiding both in strengthening the N. Atlantic equatorial whirl, and ultimately in producing deflections which are instrumental in the formation of the Gulf Stream. These matters I will separately consider, taking the conditions of the Great Northern Atlantic whirl first.

c. To follow this matter into detail, as before proposed for the S. Atlantic Ocean, we find that if we describe the largest circle possible upon a globe over the Northern Atlantic, the centre of such a circle will be in about the 25th parallel of north latitude and 40° west longitude. If we take a radius of 1500 geographical miles to the scale of the globe, the circle described with this radius would include the northern equatorial current to the south, and the same circumference continued in a westerly direction would touch a point of land near Cayenne (Salut Isle) in South America, and continuing further, would include the large islands eastward of the Caribbean Sea and onward still further, include the island of Bermuda; it would then skirt along the eastern coast of the United States of America, and include the headland of Newfoundland about St. John's; crossing the ocean to the eastward, it would include the Azores, Madeira, and the Canaries, nearly touching G. Canaria, and strike the African continent; now following a southerly direction

touch C. Blanco; leaving that cape, still skirting the
l include the Cape de Verde Isles, from which it would
starting-point in the northern equatorial current, which
ned to be the motive system acting tangentially
t northern whirl. I may note that the greatest circle
escribed in the Southern Atlantic to include the equa-
d 126 art. *e*, to be in lat. 20° S.; whereas the greatest
ntic circle is as now shown in about lat. 25° N. The
or over the entire Atlantic system is possibly about
the terrestrial equator; so that the equatorial thermal
s of the Northern and Southern Atlantic great whirl
sponds with the thermal equator; the centres of the
ar spaces being equidistant from this. But the Guinea
current, which I have yet to discuss, possibly deflects,
nce of this coast, the southern whirl further south to
Capricorn. So also the south-eastern coast of North
the Gulf Stream deflects the Northern Atlantic
irl further *south*, and the active centre of this great
ore possibly upon the *Tropic of Cancer.* The probable
hese centres being upon the southern and northern
hereafter discuss.

ume this great mass of circumscribed water to have a tertiary matters would be constantly drifted by the tangential forces exterior to the great whirl, and any lighter floating matter would be drifted to the interior area as discussed for river whirls. So that at the exterior, islands would be most readily formed by local resistances, as local cones of impression (123 art.), and in the interior we should have floating weeds as actually.

f. In the whole of the above I assume the circumscribing resistances to be equal, so as to produce a perfect whirl system. Where the resistances are evidently unequal the whirl system will only appear persistent proportionally to its freedom of area. But we may, I think, take the proposed conditions of the above area to be the *establishment of motion* about the centre of inertia of its greatest open liquid mass for the N. Atlantic Ocean and consider it subject to the collateral forces that enter only into composition with it. We may do this in the same manner, for instance, as we may assume the moon to revolve by its initial impulse directed by the earth's attraction in a circular orbit by tangential forces and attractions, quite irrespectively of the influence of another attraction, as that of the sun, or of the eccentricity of its orbit; which latter we know are forces that enter into composition, and that modify the motive directions of the primitive system we assume first taken.

128. Secondary whirl systems of the North Atlantic.

a. We may now follow the conditions of acceleration and of resistance to the motive system, proposed above, for the Northern Atlantic Ocean as a whirl system, open on one side and moving upon its axis of inertia in the greatest free area, or rather that of least friction, following the direction of forces active upon it from the effects of impulses moving directly and tangentially, as also of other forces that may act through deflection in or from the direction of its rotation at any angle of impact. Further, considering that such a system of motion suffers resistance from the interferences of all land surface, at or near, its circumference, and also loss of momentum by deflections from whirl circulation by tangential projections into direct lines, where the tangential plane meets an area of greater freedom to throw off water, which formerly impressed its forces by continuity of liquid cohesion simply, in the unit whirl system in its complete form.

b. To follow this matter as it actually exists, it appears extremely probable that if the Northern Atlantic equatorial current alone

pon the area that I have taken to be circumscribed
ginary centre in lat. 23½° N., long. 40° W., and that
Ocean supplied no auxiliary impulse, then this area
ved nearly as the Southern Atlantic whirl which I
liscussed, and instead of the powerful flowing force of
am, as it is termed, being projected at high velocity
e a whirl moving at a velocity that would be only the
n the united velocities of the southern connecting
that of the Gulf Stream. This would materially
rojectile force of the Gulf Stream as it now exists;
Connecting Current gaining, by the greater impulse
al projection assumed, exactly the force that we in
re should lose.

w continue to follow the *northern* deflections of the
ntic equatorial current, after this current is divided
e of resistance, before discussed, about St. Roque,
s off a considerable deflection into the Northern At-
e find this current, after division, directed upon the
of the South American continent at an angle of
about 25 degrees to its original projection. This
t forming the long side of a cone of solid resistance
before stated, the vertex may be represented by the

local obstructions from irregularities of the coast. However, the most important obstruction to the formation of a perfect whirl in the Gulf of Mexico, is in that, where the whirl would fairly complete its northern area, it is deflected inwards by the peninsula of Florida, and in this deflection the current is sent at a salient angle upon the large island of Cuba, which having a north-westerly directed coast causes the current to at once bifurcate obliquely, and drift its largest volume at once into the North Atlantic Ocean, directly towards the axis of the great rotary system that I have just described as being the established whirl of the Northern Atlantic oceanic system, in its greatest free area.

e. If we consider the motive lines of one part of the Southern Atlantic equatorial current in its northern deflection, to offer a plane of resistance to the northern equatorial currents, when they come in contact in nearing the Guiana coast; the northern equatorial current may then be considered to be active entirely upon the great central whirl system I have imagined about a centre in lat. 23½° N. long. 40° W. This being the case the deflected surface water of the south equatorial current, by the directions given to it by coasts, will crowd as it were into the circumference of this great whirl system, after the Mexican current leaves the Gulf; so that the southern current will strengthen the northern system, mostly, where it now impresses its impulses upon the tangential plane of the established whirl system. This impression will evidently occur after the circuit of the Mexican Gulf upon the long extent of the south-eastern coast of the United States of America, where the largest element of the united forces of both currents are impressed, which here form what is termed the *Gulf Stream*, whose force is possibly derived principally from the northern deflection of the Southern Atlantic current.

f. We may take the above probably as the principal cause of the Gulf Stream, but there are no doubt active minor impulses which materially affect the general result. Thus the great Atlantic whirl that I proposed, whose centre is in the great Sargasso Sea, and whose force I have at present only attributed to northern equatorial currents, will be generally strengthened by all currents, and by the plus rotational velocity of deflected currents proceeding from the south. The northern equatorial current itself being materially influenced and deflected by the resistance of Porto Rico and the group of islands westward; thus carrying the deflection of

along the West Indian Islands, to meet the outflow
eam proper; much earlier than that just proposed for
nt upon the great central whirl system, whose circum-
only extend directly in this part to Bermuda.
hat as there must be generally an approximately equal
vitating fluid, or of force, in all parts of a rotary liquid
to be moderately frictionless under the action of
on the globe, it is clear that the volume of southern
the tangential system of the great Northern Atlantic
t do so entirely, although it would act as an impulse
n it. Therefore the southern deflected current would
he established northern rotary system as a hydrostatic
wing the limits of the current by its impulses, but
y with increased velocity towards any more free area
hus a large portion of the flowing force derived from
ystem that we may assume acted at first as a tangen-
er the resistance of the south-eastern coast of North
celerate the great N. Atlantic whirl, would afterwards
tangentially as direct force as soon as any free
relieved the hydrostatic pressure from the circum-
established rotary system.
ears to be actually the case with the Gulf Stream,

tions, there are undercurrents present, the principles of which I will hereafter consider, or any other static water near, then under these conditions, the surface waters will have power by their free velocities to leave the central system, their places being supplied by indraught from below, or within, to complete the tangential whirl system. It is very possible a case of this kind occurs near the western coast of Portugal which supports a secondary cone of impression to the easterly deflected North Atlantic whirl current on its northern side, so that by this means only a portion of the original rotational system continues in the surface whirl towards the African coast, a large portion of the easterly deflected current, carried through the freer part of this rotary system, being split off and deflected round the Bay of Biscay. This deflected part possibly bifurcates again in meeting the general north-eastern drift of the Gulf Stream, with which it again partially reunites, and passes into the main current skirting the British Isles. In its further course, by the continuity of whirl forces, the Gulf current as a diffusional system throws off offset whirls into the English Channel, St. George's Channel, and the North Sea; and further continuing under deflection of the resistance of the coast of Norway, directly into the Arctic circle in Barends Sea, with a whirl deflection into the White Sea, where warm tropical currents may be traced all the year round.

j. Following again the direct Atlantic easterly drift at the point where it is thrown off the rotational system, previously discussed, near Newfoundland, as a great current moving in its central area through a curve from an eastern to a north-eastern direction by the deflections at its borders, we find it throws off whirls over every free space upon which the main current moves in tangential contact. Thus taking now the north-western side of this great north-easterly current, or Gulf Stream, and following its course after it leaves the coast of Newfoundland, we find it produces an immense whirl between the coasts of Labrador and Greenland; further on another to the south of Iceland, subject to deflection to the north of Iceland; and another under similar conditions on the western coast of Spitzbergen, and onward by smaller whirls to the extreme open areas of the Arctic seas; where diffusional whirls complete the direct elements of the surface projection from the great tangential deflection of the Northern Atlantic equatorial whirl system.

k. By following the principle of describing the greatest circles, and

to oceanic areas, as before, for the great whirl of Nor-
. If we again strike the largest circles that are pos-
lobe, in oceanic spaces contiguous to this, in the re-
of the Northern Atlantic upon principle discussed 82
ntre of the second large circle would occur in the
ned at the mouth of Davis' Straits, which would have
about 660 nautical miles, its centre being in lat. 55°
6° W. Referring to Berghaus' map, before mentioned,
centre in lat. 56° N., long. 45° W., but I anticipate this
be drawn inwards the amount shown in the map by
of the open oceanic area of Davis' Straits. Taking
tangential to this second circle in the next northern
may be described upon the globe in about lat. 55° N.,
the circle have a diameter of 900 nautical miles it will
and Iceland, and impinge upon the ice pack off the
f Greenland. This circle would cut into the circumfer-
t taken off the Labrador coast. Referring again to Berg-
nd the direction of current lines indicate such a centre,
e of the north-westerly directed current deflects this
hat further westward. I might carry the principle
merely offer the above cases as examples of a motive
ave already demonstrated that such systems may be

circumference, as it is in any rotary system moving by radial velocities about a centre; the circumferential parts will always have a tendency to be thrown off tangentially into any area of less resistance open to them; or to be deflected inwards, into spiral systems, by more rigid external resistances, so that spiral whirls in closed systems are produced by exterior resistances.

b. I have before noticed a concurrent condition which is universal, that where the tangential velocity becomes small, which it does by gradual loss of projectile force before a whirl projection can reach a focal point—that the prescribed area of the interior of the system will be in perfect calm; but if the velocity be very great, and the area prescribed by the whirl not of great extent, then a whirlpool will be formed which is merely a tangential deflection of the gravitative liquid mass affected by the rotary force.

c. It is not imaginable, that such monster whirl systems as occur in the Atlantic and Pacific Oceans, in their greatest free areas north and south of the equator, could be formed by any single effort of projectile force acting for a period of time, such as we may comparatively employ to produce experimental whirls, this would be quite impossible. But as the positions of the liquid masses affected on the globe remain in constant areas, and the thermal and rotational forces continue constantly active as tangential forces, with small variation of direction only with changes of season, upon the parts of the same whirl systems, there must gradually be brought about a loss of resistance from inertia of the water to the flowing tangential force which establishes local whirls. There will also be set up secondary whirl systems surrounding the larger systems to act as friction savers. Therefore the directions of the forces and local accommodations finally become permanent in the whirls, as local systems of rotary motion, and the influences of such rotary systems extend far beyond, and into, other regions distant from the tangential currents by which they were formed; as shown by principles of diffusion of whirl forces, 105 prop.

d. In all deviations of direction or deflection to form whirl systems we must remember that the whirl is formed by the *resistance*, and that this is only the least frictional form of motion to continue a current. Therefore if a fluid be quite free and open into which another like fluid is projected, the projected fluid would, after a certain time, by forming systematic lateral whirls, maintain a *direct* course so far as it was able to overcome fluid resistances.

Further, the static form of head resistance to a direct flowing current, that I term a cone of impression, will be constantly wasted away by every separate or continuous effort of direct projection upon its vertex, and by the deflections from its sides (73 prop. *d*); so that it will be, as it were, driven back into any more free area, and if there be a path bounded by induced rotary motions open for continuous projection, for the lateral fluid to move in the greatest free area, there rolling contact will be ensured, for the projectile fluid to continue its projection with small resistance, as discussed 79 prop.

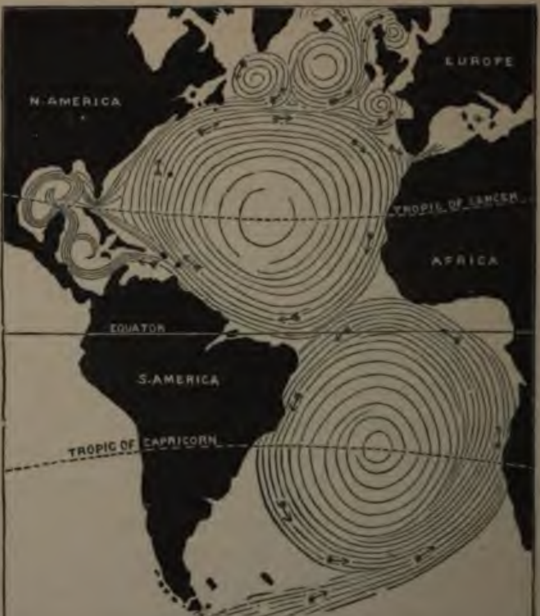


Fig. 163.—Diagrammatic Whirl Systems of the North and South Atlantic.

e. The principles here offered of oceanic circulation, as cohesive liquid systems, taking the greatest circular area of projection in the Northern and Southern Atlantic Oceans, may be represented as in the above diagram. The current lines of which, by my theory as before discussed, are nearly coincident with such lines as are generally projected on our maps. I have observed that the north-easterly directed superficial current, projected by the causes proposed in the North Atlantic, although deflected by the equatorial whirl, will be established by the constancy of the projection of the current so that it throws off a nearly direct current after leaving the coast of Florida, which moves constantly, as previously discussed, with little variation over a definite area. Under these conditions this current will have its centre constantly in the line of *least general lateral resistance*, and by this means move almost directly into the open northern oceanic area, establishing circulatory systems by leaving all lateral resistances approximately equilateral to it; consistent with such local rotational systems being established in the largest bays and most open areas.

f. It is from the above causes, that the north-easterly directed Atlantic current by the constant direction of its flow, and by the constant action of winds, which I will hereafter consider, reaches in the early autumn far into the open ocean to the south of Novaya Zemlya, and by the same causes that one winter isothermal includes the western coast of Norway in the same temperature zone as a part of England. By these principles it would also be clear that if from any cause this current should have its centre of equilibrium changed, as for instance, supposing the coast of Norway to be blocked with ice to the north, then the current would not be in equilibrium in its present eastern position, impinging obliquely on the coast of Norway, upon which, under the proposed new conditions, it could attain no freedom for its deflected waters, as then the elements of greater resistance, would by forming a new whirl, deflect the axis of the current far to the north-west of its present position; so that instead of whirl systems of very limited circumference impressing direct momentum upon our western coasts and inducing temperate climates from the North Atlantic Ocean—large oceanic whirls would be formed in this area, in front of our coasts, which would bring waters and winds after deflection from higher northern latitudes; so that Iceland, by such a deflection might enjoy the temperature approximately of Great Britain, this last having its temperature proportionally reduced, so that our seas would be loaded with northern ice.

g. I have founded the above paragraph upon the conditions of the open oceanic area to the north of Europe being wholly or partially closed, or a more westerly one opened; but at the same time we may conclude, that so long as this area is entirely oceanic, the impulses that cause the northern current, and the plus revolution velocity that gives this current an easterly drift, would at all times tend to open out this oceanic area, and even to wear away the north-

s of any land that might oppose its direct impulse;
ocal changes, as, for instance, an encroachment of the
commonly rests to the south of Bear Island, would
en the free area for flow of superficial water round the
t of Norway, and cause the biwhirl that splits over
o deflect more surface water northward into the Spitz-
and less towards the White Sea one, thereby changing
equilibrium by throwing it somewhat north-westward,
materially deteriorate the temperature of northern
so far as our coasts. Further, as the constant impulse
ter in this area is *northerly*, by thermal causes, and
gh deflection by the plus revolution velocity of the
rs moving northwards, a resistance that by any cause,
sence of land, or ice to the eastward, that overcomes
pulse, leaves only the constant northern-directed ther-
erived from the original tropical expansions and polar
which would become, by the eastward resistance, nearly
the polar liquid system after a very limited projection.
eanic systems of the earth maintain a nearly constant
th gravitation at all parts of its surface, the great North-
nt or Gulf Stream must of necessity have an accom-
countercurrent of water directed back to the area of

130. Whirl Systems of the Southern Ocean.

a. The impulses derived from thermal causes (112 art.), by which the fluids upon the globe are displaced both north and south in composition with the revolution velocity of different latitudes (114 art.), produce no doubt the greatest superficial effects within tropical areas. We find nevertheless in these areas by the actual circumstances the movements of oceanic currents are under a certain restraint from the situation of continents, the coasts of which deflect the direct momentum of such currents, under conditions already discussed. By this cause we may imagine that the diurnal thermal impulses would be altogether more powerful if they could act cumulatively, for direct projection of the aqueous system in equal open latitudes, as, for instance, that the tropical area were entirely oceanic. This condition of freedom from the interference of land we find nowhere upon a single parallel of latitude upon the surface of the globe, except in the Southern Ocean. Thus in the distribution of land in the tropical area we witness three great barriers to direct projection; those of North and South America, Africa, and the immense group of large islands extending from Sumatra to New Guinea, forming the Malay Archipelago. Further, it is not only the obstructive positions of the land, but the areas also, which may be roughly estimated to occupy the large extent of 60 degrees of longitude in the tropical band, or about one-sixth of the entire circumference of the globe, that may be conceived to cut off space from the extent of a comparatively open oceanic circulation.

b. In the Southern Ocean, taking the parallel of lat. 40° S., we find the land offering one perfect obstruction only, that of South America, and two imperfect, those of Tasmania and New Zealand. These last, as open islands, may be considered to cause deflections of currents rather than to form obstructions. The entire land area in the parallel of latitude 40° S. being only in the relative proportion of about one-twelfth that of the average tropical area, or about one-seventieth part of the circumscribing oceanic area in the same latitude. If we take a still higher latitude, say 50° south, we have here only the small interference of the land about the south of Patagonia, causing a deflection round Cape Horn. So that in this latitude we may consider we have the ocean nearly free to the action of rotational forces, which in one place only, off Cape Horn, is restricted to so narrow a limit as 10 degrees of latitude.

c. Now returning to the conditions of thermal projection from

area, previously considered, if by equatorial thermal
re formed in all the great southward oceans, the Pacific,
Indian, the southern sides of such whirls will be placed
e area of the Southern Ocean, and it is here as dis-
e South Atlantic (121 art.), that the tangential forces
ms will be set free, except inasmuch as the whirls are
their cohesion and by gravitative forces as complete
stems. Therefore we should anticipate that the tan-
rial forces would, through the southern whirl systems,
round into the free southern latitudes of the globe, a
course would be from west to east, in all the oceans of
hemisphere. Further, that this current, acting cumu-
pulses impressed through ages of time, although by
f impression of tangential whirl forces it should not
velocity, yet by continuity of similarly directed im-
he absence of direct resistances from land, it would
immense volume-force; so that its momentum would
general system of forces as a certain connecting, or
in the cosmic fluid systems of the globe. This we
as an active effect, although there are no doubt other
me of which I will yet consider), which influence the
ion of the currents formed in the manner assumed.

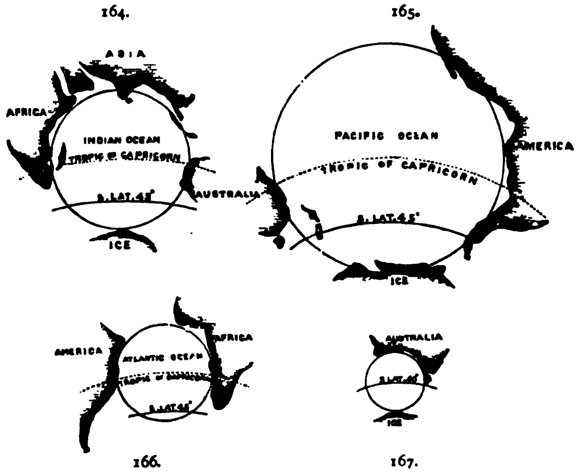
55 degrees south of the equator, or 3300 geographical miles; the Southern Pacific Ocean *eastward* of this, taken at a point central to this land resistance, at about mid distance from the equator to Cape Horn, would be in 27½° S. lat. Here the latitudinal extent of the Pacific Ocean would be about double the southern extension of land, or about 6600 miles from South America to Australia. Now taking the southern prolongation of Africa from the equator as about 34 degrees, or 2040 miles; the width of the Southern Atlantic at the mid easterly land space 17° S. lat., or from Port Seguro, South America, to Great Fish Bay in Africa, this is about 2900 miles, which is nearer in the proportion of 2 to 3; but here we may imagine shading influences from the direct impulses of the Southern Ocean in the great prolongation of South America places the circulatory system of the S. Atlantic much further south, so that it more nearly corresponds with the tropic of Capricorn where the distance between the continents of S. America and Africa is greater. If we, in conclusion, consider the Malay Archipelago in its obstructive effects upon direct currents of the Southern Ocean as somewhat equivalent to a direct prolongation of Asia into Australia and measure this with Australia, as a continent, we have about 38½ degrees of southern extension from the equator, or about 2300 geographical miles. The average mid-width of the Indian Ocean in about 19° S. lat., including Madagascar, is about 4200 miles, this proportion approaching more nearly to that of the Pacific, so that we may altogether assume that the prolongations of continents are somewhat equivalent in proportion to the extent of the oceans to the eastward of the open Southern Ocean.

f. If we take this matter in another manner supposing the formation of land areas influenced by oceanic whirl action, and describe the greatest circles possible in the great oceanic areas open to the Southern Ocean, upon principles previously discussed for the N. Atlantic, 121 art., we could thus describe in the Pacific Ocean a circle with a radius of about 3300 geographical miles from a centre upon the tropic of Capricorn in long. 142° W.; starting upon the coast of Patagonia, this would follow very approximately the entire western coast of South and North America as far as the north of California, where the coast strikes out a little from our circle, this circle continued through the N. Pacific would include the Sandwich Isles, which it would pass about 11 degrees to the northward; now turning southward it would touch the isles to the east of New Guinea, which

to the westward, and strike along the eastern coast
eaving New Zealand the only large land area outside
ntinuing the same curvature southward it would fall
he deep Antarctic bay of South Victoria, where the
eet interference from Antarctic ice, until it again fol-
mately the same curvature in continuity past Graham
s to the eastward back to our starting-point near

in the Indian Ocean the same principle as the above
le, taking again a point on the tropic of Capricorn
ld be described in about long. 80° E. with a radius
eographical miles. With this radius, in describing a
g the western Australian coast, it would skirt Suma-
northward to Ceylon, onward it would include the
f Madagascar; and continuing south, leave Kerguelen
orthward, completing its curvature in the open ocean
lia, our starting-point.
ern Atlantic I have already considered. The largest
cean could be described again upon the tropic of
bout long. 12° 30′ E. with a radius of 1400 geo-
, the circumference of which would follow very fairly
land resistance in this immense bay.

currents upon coast lines. This we may find not only in the delta-like pointing of continents towards the open Southern Ocean before proposed, but in the circumscribing forms of land witnessed in the hollow eastern and western sides of all continents; or where such hollows are not present then by groups of islands which complete the like concave forms, or induce upon oceanic currents effects which are equivalent. Further, it is not at all presumable that a few millions of years would produce the immense effects here proposed, but in the infinite past there is time enough for all changes, if causes are active to produce constant effects all in one direction as proposed. The positions of land relative to the extent of oceanic areas discussed above in paragraphs *f*, *g*, *h*, and *i*, are shown in the above diagrams, the projections being sketched from the oceanic centres given as the contiguous lands appear upon a globe.



Figs. 164–7.—Southern Equatorial Oceans projected from Centres given § *f*, *g*, *h*, and *i*.

131. Secondary biwhirl systems in open oceans.

a. I have already discussed causes that influence the shaping of delta-like continents by land resistance to flowing forces in the currents of the great circumscribing Southern Ocean 122 art. *h*, the principles of which are further assured by the evidence of actual currents and the circular form of southern equatorial oceans. Now assuming these continental deltas, by reaction, to deflect also the currents into whirl systems which are somewhat proportional in the prolongation of the continent southward; then deflections taking a large element of their motive from the open Southern Ocean, they will project pon the western sides of such continents. In this projections will be easterly to the oceanic areas, s, if continued in a complete circuit, will re-enter the n upon the *western sides* of the southern equatorial ch immense systems there will be considerable ele- om which will cause them upon re-entering to almost t projections, so that they will here encounter the he established currents of the Southern Ocean, and sistance, we shall have, the conditions necessary to in which there will be formed a cone of impression sistance of the Southern Ocean. The conditions of ng whirl currents are therefore somewhat similar to for the formation of deltas at the mouth of a river currents impress their impulses upon static or other- esisting open oceans.

ume in the manner just proposed that the release of es from a whirl system before re-entering its original nt, and meeting thereby a new resistance, to form a sion, we may imagine that such release of tangential the south-western corner of its whirl system in this bay; and in the Arabian Sea, Socotra Island. Thus, taken as a general principle, the Southern Oceanic areas have islands situated uniformly near their south-western corners, where they re-enter the more open oceanic space which I assume in a certain way to *rule* the directions of their circulation. There will necessarily be influencing causes, not here considered, producing local differences of which I may instance *magnitude* only of some of these islands. Thus we should anticipate the Pacific whirl system from its magnitude would develope the largest cone of impression or island, and impress its force the deepest into the Southern Ocean; the Indian Ocean would develope the next largest from the extent of opening of this area to the Southern Ocean, and we should assume the Southern Atlantic to be a relatively cramped system in relation to forces in the Southern Ocean, by the shading of the direct impulse by South America from the full impulse of its currents, so that here we have only the small resultant of the Falkland Isles. This matter is otherwise complicated with details I cannot now follow.

c. I hope at some future period to have an opportunity of discussing volcanic conditions from my own point of view, in which volcanic forces appear to me to follow certain laws by which the system of the globe, past and present, appears to be entirely consistent with the distribution of land and water upon its surface. Being unable to discuss this matter in a treatise upon fluids I consider this subject so far incomplete.

132. Conditions of countercurrents.

a. We may take countercurrents to represent the opposite sides of whirls or of continuous series of whirls to that from which they obtain their impulsion. Examples of these countercurrents are found in 82, 83 props. for circulatory systems, and 88, 89 for parallel systems. In such systems there will always be an axis or axes of inertiæ where the forces of impulsion and of resistance are in equilibrium, such spaces in oceanic systems being quiescent.

b. If, for the sake of division of active forces, we conceive the intertropical area to be that particularly of thermal expansions and greatest revolution velocities. Then the circumpolar areas extending to the tropics may be taken to be the areas of active contractions as they are also those of least revolution velocity. Therefore, by causes previously discussed of the action of thermal

forces, the tropics will be as lineal axes of inertiæ,
ress it, so far as the disposition or division of active
ned. In this case, supposing a whirl system formed
ocean, the thermal surface forces moving into revolu-
ould act as a broad band drawn across one side of a
on its axis. The band extending from its axle to
one tangential direction, the impulse of the lineal
band being as the radial distances of its parts from
e wheel (or whirl).

robably from observation, as well as from consistency
action of the sun's rays, and the formation of the
axes of inertiæ to the equatorial oceanic systems in
placed directly upon the *tropics*. This is also con-
s position being that on which the centres of the
circles can be drawn upon the globe, as described
rn equatorial oceans, 130 art. *f*, *g*, *h*, and for the
tic, 127 art. *c*. The same principles hold also in the
ic, which I have not discussed, but this area meets
ditions of an open ocean, in which the equatorial
cted somewhat southward by the influence of the
whirl; so that the equatorial currents of the Pacific
fall 10 to 20 degrees north of the equator. The

declination; the difference of thermal force acting in like ratio. We have, therefore, intertropical countercurrents as we have extropical ones, which are active upon equatorial lateral spaces of intermediate calm. For these there is also the influence of vertical circulation which I will subsequently discuss. The areas of equatorial countercurrents being entirely oceanic the conditions are much less complicated than those just taken, where we have interference of land. These currents form of themselves moderately parallel bands in relation to the interspaces of ocean about the thermal equator; they therefore meet the conditions of cohesive parallel fluid systems; motive upon principles discussed in 93 prop., which establishes the necessity that to every current there *must* be a countercurrent. This being also dependent upon the conditions given 88, 89, and 90 props., and of deflected whirl systems, 83 prop.

CHAPTER XII.

WHIRL SYSTEMS IN HORIZONTAL AERIAL CIR-
—ELLIPSOIDAL SYSTEMS FORMED BY COMPOSITION
L FORCES INTO SURFACE REVOLUTION—EQUA-
D POLAR PROJECTIONS.

conditions. Flexibility of aerial systems.

ring the conditions of liquid whirl systems I pointed systems of incompressible fluid maintained circular with considerable persistence (arts. 126, 127), acting of their cohesive and elastic properties to conserve tion. In aerial systems the similar directive motive from symmetrical circular whirl projections, in a highly frictional manner, and by loss of directive momentum.

b. The extent of any rotary or whirl system in an aerial fluid, as in an aqueous one, is derived from the continuity of impression of tangential forces, and subject to deflections by resistances as stated above, the forms and dimensions of aerial whirls or other circulatory systems, induced by continuity of direction of aerial tangential currents, may be therefore materially different from the oceanic systems upon which they may repose, and from which, in some cases, they may derive their impulses, as the aerial currents can evidently move over mixed, solid, and liquid surfaces which the aqueous cannot. The solid land will, nevertheless, be the most frictional and resistant, and will generally engender secondary systems of local whirls of smaller area, or diffusional systems, by the immediate action of the resistances, that produce at the time local deflections. Whereas, over the less frictional open oceanic areas, the aerial whirls induced find modes of accommodation for more extensive regular systems of forces which, after establishment, have a tendency very generally to circumscribe the entire oceanic area, as the plane of least resistance, if the forces are in any way directed tangentially to quiescent parts, the actual conditions of which, as they occur upon the globe, I will endeavour hereafter to show.

c. By the flexibility of aerial systems they are able to move more directly to the influences of thermal forces, in composition with latitude velocities, than is possible in the more cohesive aqueous systems. Further, the aerial systems are not circumscribed anywhere by *perfect* resistances, as we find in the case of the aqueous at every coast-line, therefore aerial systems form generally *ellipsoidal whirls* upon the surface of the globe upon conditions discussed, 115 art. *a.*

184. Influences of coasts upon aerial systems.

a. Accepting the conclusions given, 119 art., for the motive causes under which horizontal aerial currents, moved by the adhesion and carrying force of the surface of the ocean, follow powerfully the directions of oceanic currents, as also that the momentum and adhesion of the air moved forcibly by exterior force, has a great influence in directing ocean currents, these forces being frequently derived from the same set of causes, therefore consistent, we can imagine that in

the density of its lower stratum, that the same resis-
land which oppose the continuity of oceanic currents
nner, when the land is elevated above the oceanic level,
nilarly directed aerial currents, and deflect them also
ough not entirely. Therefore aerial currents will
w certain conditions that I have discussed for oceanic
s is further assured by the rationale of my experi-
abundantly show that air and water move in systems
ections, under like or equivalent resistances that may
n their masses, under all the conditions previously

e same conditions, the denser lower air resting upon
be to the resistances of elevated surrounding parts of
h it were inclosed in a containing vessel, as discussed
c systems in the great oceans; and under this con-
nce to the direct thermal and rotational influences
circumscribing equatorial currents, will cause deflec-
evations of land as previously shown for oceanic
therefore by like circumstances most of the conditions
ems must be induced, as were discussed for aqueous
st chapter, subject in this case for air, that the cir-
sistances cannot produce anywhere *perfect* resistance,

current inland, as before stated, and the continuity of the backward force of the motive system, both aerial and liquid, may continue to propel the air inland until it encounters resistance in general equation with the backward forces of propulsion.

d. If we imagine a motive system consisting of the entire air resting above an extensive liquid, the surface of which is moving at the same rate as the air—a quite possible condition—the air will form a gravitating system whose mass momentum will represent, as before shown, a force of about 2000 lbs. per superficial foot over the earth's surface. This moving mass may be propelled forward by thermal or other causes at 20 miles or more per hour in streams many miles in width, and in this manner represent a force scarcely calculable. Such direct momentum induced in an extensive aerial system cannot possibly follow all the minor surface motions of the ocean; for instance, the deflections caused by a rugged coast, but will carry forward its direct impulse almost entirely over the coast lines, as before stated.

e. Where the aerial momentum carries the wind force directly over a coast after the wind has overcome this resistance, it will be, if *impulsive*, a free projection that may be strengthened by the following parts being projected in like manner, or, if *constant*, it may by its direct momentum draw after it backward parts, as before stated, so that as a general resultant a continuous system of motion will be induced, by the cumulative action of forces in local parts. This will be particularly apparent near coasts where directive oceanic currents are known to prevail, as for instance on the western coasts of Ireland, to south-westerly winds, which are found to prevail inland as well as upon the coasts.

135. Influences of aqueous areas upon the direction of aerial forces.

a. The reciprocal action of thermal forces in moving fluids upon the globe from and towards the tropics and polar areas (112 art. *f*, *g*) will be naturally subject to such resistances as may be offered at the surface of the globe. This will be particularly evident in aerial fluids, which increase in density in proportion to the compression of air above any stratum, by which half the gravitating atmosphere remains within 3·6 miles of sea-level (art. 116, *b*), a less altitude than some of our highest mountains. Therefore it will be quite clear that land, independently of its irregularity and frictional

'er in many cases nearly absolute obstruction to lower
urrents.

ıown (art. 112) that although the force of expansion
eat at the tropics must be in equilibrium with the
ıction by radiation in circumpolar areas, particularly
or the atmosphere to remain at the same average
the expansive force of the tropical system will be
greatest penetration from its diurnal impulsive charac-
influence of the revolution of the globe (112 art. *h*).
ɔy the conditions of fluid forces moving toward equi-
h the paths of least resistance only (art. 112, *f*), there
y be formed in every natural aerial system, through
ies of the surface of the globe, *set courses* in which
ve with the least resistance; and as the parts of the
ɔermanent these may be discoverable by observation.
v consider the uniformly level surface of the ocean,
gether the minor irregularities of a few feet in surface
this evidently a less frictional surface than the land
th various inclinations. Therefore the same land,
ı the previous chapter, which offers *perfect* resistance
rs, will offer *partial* resistance to motive air; and so
stance is active, aqueous and aerial systems moved by

one direction; the impulse of such currents as are formed continuing active by the momentum they carry over and beyond frictional resistances. In this manner the superoceanic currents at all times form the means of supply of air to polar areas; whereas the return or counter currents, from the oceanic space being already occupied by the equatorial impulsive projections, almost universally move over the near continental areas. In this manner also the condensations of air in winter over the great continental areas of radiation, of which, in the north, central Siberia forms the centre, attain supply through the Atlantic currents where the atmosphere moves with the greatest freedom, therefore in the greatest continuity. And it is to the influence of the indraught of such superoceanic currents toward circumpolar regions that the temperature of North-western Europe is so high at the decline of the year. Whereas by the same principles of continuity of induced motions in the directive momentum of the fluids, *the established currents resist the return in this same direction with the return of spring, so that the expansions by the sun's heat over the former areas of contraction are with greater facility moved over land areas where there is no aerial direction in opposition.* Except in the advanced spring, when the northern thermal expansions quite overpower all resistances, by the increase of altitude of the sun, which moves the air by its expansion in a south-westerly direction over nearly all northern areas.

f. The courses that aerial currents take are not difficult to be observed, by the condition of the air at any point, in the amount of vapour the wind carries, as we find such aerial currents moving over the great oceans are saturated, or approximately so, by the evaporation at the oceanic surface, and when drifted on land are always moist, and ready upon any decrease of temperature to produce rain or snow. Whereas currents deflected from circumpolar land, particularly from the higher latitudes, after a certain distance have the moisture that they previously contained already largely reduced by condensation. The direction of these currents being clearly indicated by a line of dry air throughout their courses in the whole area of their return to the equator, except within nearly the extreme polar limits.

g. The directions of aerial currents into polar regions are equally clear by the warmth they carry with them, as also by the volume of vapour under constant condensation in which the vapour system latent heat and further warms the air by its condensa- in rain, and still more so, if condensed to snow.

above conditions we may conceive the causes of a direction being given to equatorial aerial fluids into emisphere over oceanic areas; but the resistances that rents from polar areas, redirecting them towards the not be so clearly defined locally, as these will neces- land areas, assuming the oceanic to be occupied by jections as before. In this direction of their course ow the influences of resistances which present to them on in such manner as they may complete the circula- continental area.

condition of equatorial projections being the ruling one cause that is permanent, besides the diurnal im- ter of the projection, which is, that the thermal equa- presents an area of the entire surface of the globe tropics; whereas the areas of condensation, that is, as, are relatively small, by the space between any constantly decreasing from equator to pole. There- l fluids directed to polar areas have their amplitudes ricted in such areas, and thereby produce a conden- lastic system, sufficient to form a resistance and cause ensured in that flowing fluids under resistance have in flowing in one direction, power to engender very frictionless forms of accommodation to their motions by whirls, and by the momentum of these as well as by the currents, to offer considerable resistance to any system of *reversal* of their direction as before mentioned, so that when these reversals are possible they are generally brought about, not by inducing at once an opposite direction, but by *some form of deflection*, by which the induced motion continues its motive lines, although through a certain circuit in the fluid system.

b. Upon the above principles, aerial and aqueous fluids generally have power to maintain motive evidences of forces impressed upon them a long period before, so that they do not readily come to rest in equilibrium with the forces that are immediately impressed upon them. This principle is particularly evident where the motive system and its resistance is entirely fluid, as in air moving over oceanic surface, the effect of which is observable in such instances as the maintenance of open polar oceans by currents whose temperature plainly points to a motive source very distant in tropical latitudes, which continues active above the resisting influences and effects of seasonal obliquity.

c. Over land surfaces, aerial currents present somewhat opposite conditions, from the effects of radiation. These surfaces in large continents have a tendency by the constant local intermittent efforts of expansion and contraction in the air, diurnally caused by the alternate action of the sun's and the earth's radiation, to bring about everywhere over continental areas where the sun's force is active, a state of local equilibrium. This principle of oscillation of temperatures, or of expansive forces, forwards and backwards over the point of equilibrium in inland areas, resembles the vibration that we apply to scale beams, to produce the equilibrium of rest, when such are in motions of great amplitude. In like manner these terrestrial areas if isolated from oceanic influences rest diurnally on an average in equilibrium, in consonance approximately with the sun's influence upon the surface exposed and the earth's radiation. The same sun's rays which according to season act obliquely to the earth's surface cover a larger area, as before stated, in inverse proportion of the radius to the sine of the obliquity; omitting conditions of differences of diathermacy of the air in the obliquity of the ray path, clouds, and other minor conditions.

d. If we conceive the principles established, that I have offered

of expansile aerial and vapour forces over the equa-
and contractile forces over polar regions, and of such
dering counter currents, particularly for the return
air deprived of its vapour by condensations; we may
ere will be established by cumulative efforts of diurnal
nfluences, certain conditions of continuity of motion
ssible in a circuit, in which, as before discussed, the
ill move in the planes of least resistance, wherein the
of original projection takes the area of least resist-
tablishment of its currents. Such circuits in the isola-
parts meet the conditions of whirls engendered or
ential forces of exterior currents, and where the equa-
ojection takes as actually the oceanic area the part
that forms the countercurrent may become neces-
overland. Further by the continuity of the whirl
oceanic surface the overland aerial current receives
ctive impulse and becomes in certain cases as per-
ity as the oceanic one.

on of aerial forces.

ial forces have not sufficient momentum to overcome
in order to form a circulatory whirl system, their

forces of the sun and earth act with greatest intensity, producing, according to the circumstances, hot or cold districts.

c. This diffusional motion of air is a very common form of projection for winds, even in close areas, and is very observable with a little care in many cases. From my window as I sit writing I can observe a large number of tall trees at different distances. The wind, although it is in its general direction southerly, is veering and backing most unequally as the restless weather-cock indicates, so that when distant trees are in motion, near ones are quite still, and *vice versâ*. I can, even after watching for a few minutes, anticipate which of the trees will move next. One particular tree, a young willow of about 40 feet in height, appears to be blown periodically at intervals of about 50 seconds apart. I plumb this tree by a blind line that hangs in the centre of my window. I find that when it is blown, it bends for about 12 seconds to the westward of south, then rests apparently quiet for about 35 seconds, and then again for about two or three seconds it blows to the eastward of south; the moving parts appear to describe ellipses.

d. It is quite natural that by feelings upon our small bodies we should take it for granted that winds blow directly, but whenever the motion of the wind is made visible from any cause, as in the carrying of autumn leaves or dust, it becomes at once clear that winds move very generally in curves, often in very small visible whirls. When such whirls have broken up the aerial resistance, there will be direct central currents, and the diffusional whirls will exist at the front and sides of such currents only. But this principle of motion will be fully developed at every entering or displacing aerial current where a lineal current of projection is not established, however extensive the area, the whirls themselves being proportional to the force of projection, although composed very generally of an almost infinite series of smaller internal whirl systems (109 remarks, *f*).

138. Comparisons of actual areas of resistance upon the surface of the globe to systems of aerial forces.

a. Following the general principles above discussed, if we take the conditions of free oceanic areas and the forms of continents that are actual upon the surface of the globe, we find that we have in the northern hemisphere two large, although unequal oceanic areas, which will be the natural areas of thermal projection in this m causes discussed, offering the greatest facility of erial currents, that of the North Pacific and that of ntic. Over these oceans inwards towards the thermal northern tropics we have the inflow of the lower in a southwesterly course in the well-known tradensiderable part of the tropical area, most particularly n sides of these oceans. This inflow from the oppof like inflow at the equator from the southern hemim the excess of rotational velocity in the equatorial t.) deflects the inflowing aerial currents to a westerly we have near each side of the thermal equator, over of the great northern oceans, two zones of nearly n directed aerial drift, or easterly wind, which we self to represent a considerable force as active upon ent contiguous circumpolar parts of the aerial system

ow the general positions and configurations of the y act as resistances in relation to the less frictional reas of the North Atlantic and North Pacific oceans drift of the aerial currents considered above; we find rial continental land systems in opposite areas of the sphere, are very approximately alike upon their tion of the land area into the Sea of Okhotsk, this direction will be much more nearly coincident with that of the North Atlantic western coasts, particularly if we recognize the influence of Iceland upon the general equilibrium of land distribution, and possibly the superior elevation of the interior of Greenland. In this manner we may observe that so far as the land areas are situated in relation to equatorial currents under thermal and revolution influences, that the deflections of direct flowing aerial forces impinging upon these areas from any cause will be similar in the Pacific and Atlantic systems; and that if the general principles of motion in the air support a system of equal deflection of impulses from land, such a system will divide the northern hemisphere into two not very unequal aerial systems of projection and deflection, the further conditions of which I will presently consider.

d. If we examine the areas of resistance in the southern hemisphere we find the land occupies much less area, and that the oceanic systems are divided into three parts which are comparable in magnitude with the northern oceans, so that by the theory of the ocean being less frictional to aerial motions, we should here expect to have three aerial whirl systems established which would be comparable with the northern systems. We have, however, in this area the Southern Ocean uniting the whole liquid system, thereby rendering the general principles that I shall endeavour to define for the northern area, more open to compensations. Further, from the motive continuity or cumulative action of the aerial forces over this larger open southern system, the whirls produced are more free from local resistances, and therefore take more nearly circular forms.

e. To classify general conditions as much as possible I may observe that the entire configuration of the Southern Atlantic Ocean is very comparable with the Northern in size and form, and the same may be observed of the Southern and Northern Pacific, both oceans being open to each other at the equator; so that if the whole area of the Indian Ocean were converted into land from the equator to the south pole, there would be a general equilibrium in the terrestrial and aqueous systems of both hemispheres; but as it is the Indian Ocean may be conceived to form an exception to this general condition of form, that holds in the other four great oceanic areas.

f. An active division of the Pacific and Atlantic Oceans equatorially may, in a certain way, be assumed to be produced by natural thermal effects, together with the action of revolutional velocities

nt systems induced thereby, which render the northern
hemispheres motively separate systems. There is,
ven in this case, undoubtedly a reciprocity of action in
f forces both in the Atlantic and Pacific Oceans on
he equator, wherein we have *ruling systems* of forces
resistances, the particulars of which I will now sep-
er.

whirl system of the Northern Atlantic.

flection of southern equatorial *oceanic* currents north-
essed the powerful directive influence of the north-
of South America (127 art.). This same coast-line
especially adapted to deflect an aerial current im-
t it, by the position of the land towards the sea, backed
lly by the S. Francisco range of mountains, which
ds the sea near Aracuti and Quinta; thus presenting
sing front to the continuity of the westerly impulse
equatorial aerial currents. We may assume a cone
to be formed about the same point of St. Roque,
thern equatorial aerial currents possibly divide, in a
to that previously discussed for the aqueous system.
n a portion of the southern equatorial aerial impulse

is probable, a system of aerial deflection is formed which includes currents within 5000 or 6000 feet over the entire eastern parts of North America, these currents generally taking a somewhat north-easterly direction.

b. We may also imagine as secondary to the above system, and independently, as it were, of this great range of total resistance by mountainous land, within which half the mass in altitude of the moving atmosphere present may be deflected from its western drift (116 art. *b.*) the lower strata of the air encountering the considerable partial resistance by land surfaces in lower currents, from obstructions due to the irregularities of inclination of surface and by local resistance of rocks, trees, and every projecting object thereon; by the effects of which it will be seen, that it is over the oceanic areas only, as before stated, that we must look for the establishment of the most constant lower currents, that are palpable to us in our position upon the surface of the earth; and here the condition of aerial projection will naturally most nearly approach the direction of the oceanic systems previously discussed.

c. The continuity of induced motion being best supported upon the lower oceanic surface where the aerial fluids are more dense, together with the influence of motion of the liquid plane itself, on which these denser aerial fluids rest, represent powerful forces relative to the entire inertia of the mass of air and vapour above to deflect and project this in the same directions as previously proposed for the aqueous drift. So that it becomes probable that very large elements of the lower strata of western aerial drift follow closely the oceanic currents, making whirls of larger extent only over the near coasts by their freer tangential forces and less perfect resistances, there being no perfect resistance by the coast to aerial motions. Therefore these lower currents from all causes issue under equatorial deflections with a large element of their original momentum into northern areas approximately parallel with, and not far from the Gulf-stream.

d. If we assume the Gulf-stream a starting-point to easterly aerial drift and continue the projection in whirls as previously discussed for oceanic systems from this stream, we shall have a general flow of the aerial currents into temperate latitudes in a north-easterly direction tangential to the great free oceanic spaces; much of the aerial directive impulse being derived, as before pointed out for the aqueous system, *directly from the minus surface revolution*

m causes discussed, offering the greatest facility of
erial currents, that of the North Pacific and that of
ntic. Over these oceans inwards towards the thermal
northern tropics we have the inflow of the lower
in a southwesterly course in the well-known trade-
nsiderable part of the tropical area, most particularly
n sides of these oceans. This inflow from the oppo-
f like inflow at the equator from the southern hemi-
m the excess of rotational velocity in the equatorial
t.) deflects the inflowing aerial currents to a westerly
we have near each side of the thermal equator, over
of the great northern oceans, two zones of nearly
n directed aerial drift, or easterly wind, which we
self to represent a considerable force as active upon
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d. If we examine the areas of resistance in the southern hemisphere we find the land occupies much less area, and that the oceanic systems are divided into three parts which are comparable in magnitude with the northern oceans, so that by the theory of the ocean being less frictional to aerial motions, we should here expect to have three aerial whirl systems established which would be comparable with the northern systems. We have, however, in this area the Southern Ocean uniting the whole liquid system, thereby rendering the general principles that I shall endeavour to define for the northern area, more open to compensations. Further, from the motive continuity or cumulative action of the aerial forces over this larger open southern system, the whirls produced are more free from local resistances, and therefore take more nearly circular forms.

e. To classify general conditions as much as possible I may observe that the entire configuration of the Southern Atlantic Ocean is very comparable with the Northern in size and form, and the same may be observed of the Southern and Northern Pacific, both oceans being open to each other at the equator; so that if the whole area of the Indian Ocean were converted into land from the equator to the south pole, there would be a general equilibrium in the terrestrial and aqueous systems of both hemispheres; but as it is the Indian Ocean may be conceived to form an exception to this general condition of form, that holds in the other four great oceanic areas.

f. An active division of the Pacific and Atlantic Oceans equatorially may, in a certain way, be assumed to be produced by natural thermal effects, together with the action of revolutional velocities

Atlantic, it would no doubt be more active through-
year in deflecting aerial currents, if this land were
that of America, and were of equal altitude inland;
g an island, there is less perfect or continuous resist-
ontinuity of coast-line, and it therefore acts with
orce in deflecting southern equatorial currents,
is no doubt it acts by its inclination to the equator
r as to direct some part of the southern trade-winds
ering thereby aerial currents of the northern hemi-
he influence of this deflection somewhat stronger,
e northern Pacific climate warmer than it would be
other direction of its northerly coast-line.
follow the conditions of active equatorial forces in
ea of trade-winds in the North Pacific Ocean, we
e broad extent of this ocean, a much larger area of
ction without interference of land resistance than in
tic. We have also in this area similar conditions of
Malay Archipelago to those of the Isthmus of Pa-
orth Atlantic system, although these resistances are
mplete, the sea being even quite open in the Straits
herefore the general conditions of land resistance
ts, although great, is less perfect here than in the

with nearly equal force in so far as the equatorial impulse in their currents is concerned.

e. After the North Pacific aerial currents are deflected from equatorial impulse by the Malay Arcipelago, upon principles discussed for the Atlantic area, into the China Sea there is a moderately frictionless path open through the seas of Japan, Okhotsk, and Behring Sea over Northern Alaska into the Arctic Ocean by Melville Sound, returning to complete the whirl through Baffin's Bay, Davis Straits, over the lower parts of Labrador and Canada, and back into the Pacific equatorial system, thus completing the same form of immense whirl as that proposed for the Atlantic aerial system.

f. It appears to me extremely probable that at some not very distant geological period the whole of the Eastern Archipelago was an united system of land offering perfect resistance to the impulse of the western aqueous and aerial drift of the Pacific. I conceive this by the perfect systematic direction of the water-way between Behring's Sea and Davis Straits. Under such conditions of perfect resistance, in comparison with the Asiatic continent, the aerial and aqueous deflections would be immensely greater than at present; as currents would follow, generally, in the direction just pointed out instead of the more cramped inner system of the western coast of North America. Under these assumed former conditions, by the perfect deflection from the Western Pacific, warm currents would flow into the Arctic regions, an open sea would be maintained through to Davis Straits, and the Arctic islands of North America, and even part of Greenland would enjoy the temperate climate of Bear Island off Spitzbergen, in the Arctic circle; where cereals in favourable seasons are said to ripen grain on southern slopes.

141. Equivalence of the North Atlantic and North Pacific aerial systems.

a. The deflection of aerial currents is evidently, by the conditions proposed in previous paragraphs, under much less restraint than oceanic deflection, which at every coast-line becomes absolute; so that we find the aerial impulse, although following by preference an open oceanic area, may be continued beyond a coast, that aerial whirl systems generally will be naturally of larger dimensions and may often entirely circumscribe aqueous ones. We also find that the open area of the ocean, which may present by the direction

s a less frictional path for an oceanic whirl, may not be
nal for a superimposed aerial one, if in this there is much
ion of direct momentum. The least frictional course
will be in preference by deflection to greater curva-
ial momentum to carry the wind over the coast-line as
nd thus direct the aerial impulse inland as we may
e to actually occur within limited local conditions
our coasts.

whole of the conditions given above, in the Northern
acific aerial whirls, which I have taken for illustra-
the generative thermal forces induce whirl forms
ances and the necessities for a moderately friction-
of the equatorial current, these whirls as circulatory
vertheless motive under the enormous restraint of the
latitude velocity, which varies from about 1000 miles
e equator to zero at the poles, giving to the winds
nal displacement, possibly as Sir J. Herschel has
-thirds of their force; so that the deflected thermal
northward is constantly gaining eastward impulse
e motive surface of the earth, until as before proposed,
rly a due east wind; whereas, by the continuity of the
forces, the northern or overland supply current is car-

currents in the more open oceanic area south of the equator. In either case these foci would follow the influence of the seasonal altitude of the sun. I have conceived the following diagram to represent the direction of forces active in the aerial system upon principles discussed for the general direction of circumscribing areas in the Northern Atlantic and Pacific systems, subject to local deflections, from elevation of land, and other conditional circumstances, at about the summer solstice. In this sketch I assume other forces may be active or may enter into composition, therefore it represents only my theoretical ideas of cosmical aerial motion.

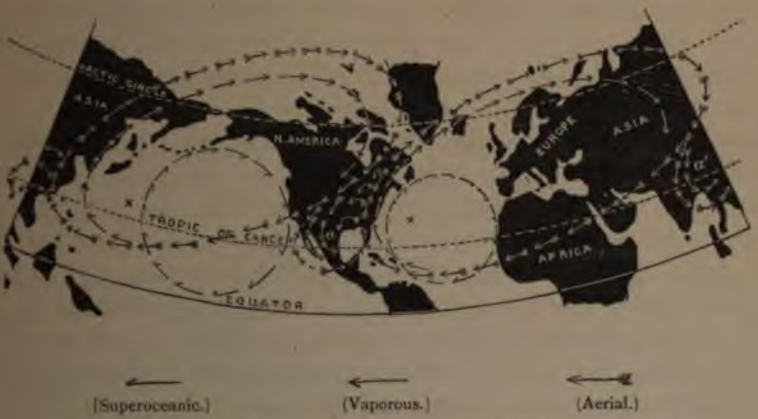

Fig. 168.—Diagram—Theoretical Aerial Systems in the Northern Hemisphere.

c. In the above diagram the arrow with one barb represents the influence of primitive oceanic whirls, directing the superimposed aerial systems by carrying force.

The arrow with two barbs represents the vapour system, in its circuit of greatest activity, falling generally somewhat short of the aerial projection, but subject to certain conditions of vertically directed forces to be hereafter considered.

The feathered arrows represent the active extent of the great superimposed aerial whirl systems of the Atlantic and Pacific Oceans which circumscribe inner systems, although not by definite lines.

The crosses represent assumed foci of the ellipsoidal whirl systems.

a a′, Regions not entering into the great ellipsoidal whirl systems where possibly biwhirls throw off a portion of the tangential force from the ellipsoidal systems. Regions of the origin of storms and hurricanes to be hereafter considered.

In making this diagram the large group of islands to the north of Hudson's Bay were inadvertently omitted, as also the arctic continent north of N. Lincoln, this omission will, however, in no way interfere with the plan of the systems proposed.

d. By observation of the isothermal lines given in Dr. A. K. Johnston's climatological chart, the entrance of the return path of the Pacific whirl, here proposed, would appear to be in about 42° N. lat. upon the western coast of America, between Fort George and Fort Ross. The oceanic bifurcation does not occur until 30° N. lat. or 12° southward of the first point. Winds deflected round the coast are common in about 35° N. lat. They should by my theory commence in about 31° N., but I anticipate the chain of the Rocky Mountains deflects these currents throwing them southwards and upwards, the same directive influence being also produced by California and the Gulf of Mexico. I have not attempted to describe the exterior deflections of these ellipsoidal systems, nor the filling in of their whirl systems. It is most probable that the inner deflections of the whirls, as they approach the foci indicated for each separate system, would become much more nearly circular, so that the inner aerial system would be inscribed by one that would more nearly resemble the aqueous; but the whole discussion is merely intended to point out a principle of motion, that by my theory would be necessarily induced, in an expansile and contractile aerial system, in relation to actual areas of friction and deflection under the impulses of different latitude velocities of the earth; as also by the functions of motive tangential forces, active upon lateral aerial fluid masses upon principles discussed in this treatise, under conditions showing that fluids cannot slip or glide upon each other without immense friction, and therefore must, if free, move by some system of rotation. In the advancing summer, by the expansion of air over continental areas, the superoceanic circulation is more restricted, and the countercurrents are deflected by resistance to closer systems, returning in areas more nearly contiguous to their oceanic projections, some conditions of which I will consider further on.

e. The deflection of aerial rotary systems immediately from the equator, by reasons I will hereafter discuss, will be at a greater elevation than the inflowing cooler denser currents, so that the plane of the whirls will be *oblique*, as I will hereafter endeavour to show.

There will be also internal bifurcations; but possibly at a few thousand feet of elevation, where freedom is more equal throughout the system, and where the earth's power of condensing heat has less influence, the currents will proceed in nearly horizontal planes on average very nearly in the directions shown in the engraving, for the circumscribing systems. There will necessarily be also northern foci to the ellipsoidal systems, which by the circuit of forces will be centres of relative repose. Assuming no seasonal force changes the position of such foci, they would receive no part of the equatorial currents, and would therefore become very cold spots on the surface of the earth, particularly as vapour condensation would be absent, the vapour currents being drifted only round such foci at a distance.

f. On the other hand near the equatorial foci would be areas of intense heat, but these being actually oceanic, the heat would largely disappear in vapour expansions at the liquid surface; protection from sun's direct rays being also produced by the formation of cloud above, therefore the heat effects would not be measurable by our thermometers at the surface of the globe, or outwardly in any manner except that it would generate overflowing vapour forces in rains and storms, which would appear in the near or distant parts of the rotatorial system thrown tangentially some distance from the relatively quiescent foci.

142. Indian oceanic aerial system north of the equator.

a. The portion of the Indian oceanic aerial system north of the equator, will, on a small scale, resemble that of the Pacific Ocean, but the former being more directly under the influence of land surface to the north, will be more particularly affected by the influence of the seasonal obliquity of the earth. Thus in our summer, when the sun's rays are nearly or quite vertical to the tropic of Cancer, the greatest heat will be distributed almost entirely over the land areas of Arabia, India, and a part of China; at such times, from the land retaining the heat forces immediately at its surface, this area becomes as the thermal equatorial zone to the Indian oceanic system. Therefore during our summer the circulation of aerial currents in the Indian Ocean meet certain conditions of circulation in the Southern Ocean which I have yet to discuss. But in the southern summer when the thermal equator of this district is entirely over the oceanic area to the south of the Indian Ocean, the conditions

the North Pacific are more nearly coincident, and
ern trade-winds in the Indian Ocean move over
s areas, with direct momentum upon the high table-
Somauli, and Hadramaut. Under these conditions
quatorial currents, by inland resistances, are possibly
ugh the back of the Indian Peninsula, by the valley
o that of the Ganges, returning to the Indian Ocean,
similar although closer whirl system, than that of the
c or North Pacific Oceans before discussed (140 art.).
bove conditions the Northern Hemisphere possesses
ulatory systems in the northern summer, those of the
Pacific, but in the northern winter, from the movement
the thermal equator further south, the Indian oceanic
becomes also one of the northern systems, and it is
e effects of this change we owe some of the stormy
ertain districts of India.

systems of the Southern Hemisphere.

mation will not permit me to offer more than a few
pon this subject. But there is no doubt, I think, that
emisphere being for the most part oceanic, that the
reposing thereon will be more influenced by the

the polar forces will more largely prevail than these forces in the north, the equatorial forces being proportionately less, as previously discussed for oceanic systems, 130 art. *a*, *b*. In the south also a large element of the circulatory aerial systems of the southern oceans appears to be derived from the Antarctic drift due to vertical circulation, that I have yet to discuss, which sets in especially upon the western coasts of South America, Africa, and Australia, the aerial systems being nearly superimposed upon the oceanic. This condition may at least be assumed to prevail upon the immense area of the Pacific Ocean; the thermal equator forming always one limit of the aerial circulation where tangential forces are most active upon the system. These tangential forces also tend in all cases to throw the aerial fluids for some distance inland of oceanic boundaries, the evidence of which is found in the amount of rainfall and vapour near the coasts.

c. The South Atlantic aerial system following the impulse of the southern equatorial current is possibly for the most part deflected to the northward past Cape St. Roque, where the oceanic system bifurcates; the greatest aerial impulse of thermal forces being carried to the westward as far as the mouth of the Amazon. The cone of resistance to this system forming its base upon the mountains of Acarai; the southern tropical aerial whirl being thrown along the valley of the Amazon, to the east of Sierra Nevada into the valley of La Plata, completing an ellipsoidal course in the south Atlantic as far as the 40th parallel, by again turning inward to the Cape of Good Hope, in every way similar to the ellipsoidal systems discussed for northern areas, although not of equal extent. The whirl gaining force from the open currents of the Southern Ocean by forming a projection similar to the oceanic.

d. The Indian superoceanic aerial system is much more complicated by the mountainous interior of Africa lying between 30° and 40° W. long., but here there is evidence of the influence of the tropical impulse over the less frictional area of the Indian Ocean upon the mountainous interior which deflects the vaporous air to form the immense lakes of Albert Nyanza, Victoria Nyanza, Tanganyika, and Nyassa, in continuing, as before, an ellipsoidal system which completes its circumference in the Indian Ocean and the western coast of Australia back into the equatorial zone.

e. In assuming the deflections of tropical aerial western drift to be caused by the elevated lands of Central, North, and South

west of the thermal zone, we witness by biwhirl deflec-
nditions in the fluviatile system on both sides of this
hus the Amazon passing with its immense valley to
uth America in a south-easterly course meeting the
lata whose direction is south-easterly, resembles the
it continues in the Missouri in a north-westerly
west of North America, meeting Hudson's Bay and
rth-easterly direction, or in taking a nearer circuit in
i proper into the valley of the St. Lawrence. These
I conceive evidently indicate the courses of vapor-
from tropical impulses.

possibly be imagined that if such systems as those
e were entirely cut off from further volcanic influences,
nensity of time by erosion from rainfall, the eastern
of both North and South America might be detached
ich would then find equivalence in the present con-
ua, and the Japan islands in the Pacific system, and
r in the Indian oceanic system. Under such condi-
mus of Panama receiving a more powerful impulse
e open equatorial oceanic and aerial currents would
sted away, and conditions similar to those we witness
Archipelago be established.

under very exceptional internal geographical circumstances not here considered.

144. Whirl areas complementary to the Ellipsoidal aerial systems of the northern hemisphere.

a. If we take the two great aerial systems proposed, of which the diagram, Fig. 168, is an illustration. There will be seen intervening spaces westward of the equatorial foci of greatest activity of these systems just exterior to the tropics; and as the motive fluids in these regions present frictional surfaces by difference of velocity of parts, they must find accommodation for such motions as in other cases considered, and systems of direction of forces must be established here as elsewhere. These spaces are shown at *a*, *a*′ on the diagram (Fig. 168), proposed to illustrate the summer condition in this hemisphere. It is most probable that the interspaces between the great Atlantic and Pacific systems are filled up by large offset variable whirls projected from the return side of the great ellipsoidal systems. If we take the interspace system marked *a* shown in the centre of the diagram (Fig. 168), we find from this, that the Pacific whirl after crossing North America meets and compounds with a like whirl from the Atlantic system, the direction of curvatures of the spirals formed being alike in both cases. This whirl system may be as shown in the diagram below, which is intended to represent, in principle, the meeting of the ellipsoidal systems about the Gulf of Mexico drawn south upwards.

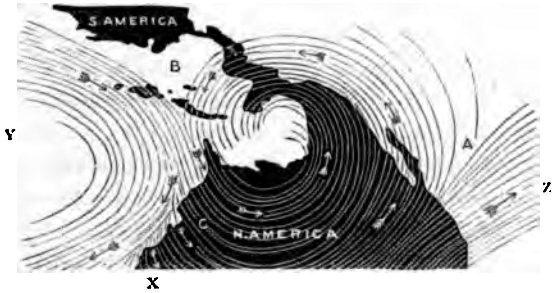

Fig. 169.—Diagram—Interspace Whirl, North Atlantic and Pacific Interspace System, south upwards.

b. In this diagram the Atlantic whirl system is shown to the left of the Fig. at Y, and a part of the Pacific return whirl system at the lower corner to the right about Z. The part of this return whirl shown at A, has its tangential force partially released, which causes e and throw off a whirl in the interspace of the great stems about this part which acts as the cone of impres- biwhirl by the resistance of the inertia of compressed in front; this point A, by conditions here given not of any rotary system. The biwhirl deflections are A to B and onwards to C, where the tangential Atlantic ellipsoidal system unite and form another hown at the bottom of the figure at X. The elliptions move as here proposed at their circumference by lling contact upon the contiguous parts, such whirls by deflection the interspace between the Pacific and rl systems. In drawing this whirl on wood which I y as a diagram, I neglected the evident influence of he globe upon its system. It should really take a iquity in a direction parallel to the great ellipsoidal here should be a secondary biwhirl to the right of the n this case the Atlantic whirl system would extend the Gulf of Mexico, entering the land near the mouth sippi river. From the Pacific coast current, represented of the figure, being subject to diffusional influences by he coast and mountains inland, the diagram as regards tions is purely theoretical and given to define a prininactive in the northern summer, but here again we have great complexity of local interferences which would require special study to define anything more than the general principles, which would be possibly only similar to those given for the Mexican area.

e. Under any conditions, as in the interspaces between the great ellipsoidal whirl systems proposed of the Pacific and North Atlantic Oceans, the interspace whirls would be formed of aerial matter thrown off or set in revolution by the one system or the other, according to seasonal obliquity, and the influence of distribution of elevated land resistances; the entire region of such interspace whirls being one of great climatic changes. In what we may term the *Gulf of Mexico whirl system*, the tangential forces from the North Atlantic whirl would throw in heat currents. Whereas the Pacific whirl system would throw in cold currents, and there would be induced from the change of the position of the heat zone by seasonal obliquity, displacement of the great ellipsoidal systems, which would cause them to seek accommodation according to the conditions of local resistance from the distribution and elevation of land, so that interior whirls or diffusional currents could only be traced with great difficulty to systematic causes.

f. I have shown one interspace whirl as representing a principle, but from interfering causes, such as mountainous districts, and general irregularities of surface, I have no doubt that this whirl is split up into many others, and that the system of projection over a large portion of the area becomes entirely diffusional, except possibly at great altitudes. Further, the seasonal obliquity, which entirely displaces the great ellipsoidal systems, changes also their general configuration. In this case by the conditions of a whirl taking the greatest circular area (82 prop.), when in the northern winter the heat zone is southward, the Atlantic whirl finds greater freedom by longitudinal contraction, and the Pacific whirl by longitudinal extension, which places the Mexican Gulf interspace system more nearly under the cooling influence of the Pacific system.

g. There is also a further condition, that by longitudinal contraction of the North Atlantic aerial system in winter, the Alleghany Mountains commence to block the tangential deflection of the North Atlantic whirl, which blocking gives greater freedom to the Pacific projection. It is probably to this cause partly that north-eastern America owes its intensely cold winters.

h. The eastern complementary system, in which I have shown the

whirl at *a'* to the right of the engraving (Fig. 168)
hown too far westward, as in this position the aerial
encounter the immense resistance of the elevated
t, of over 5000 feet above the sea-level, independently
ountains rising still higher in this district. In this
probable the complementary whirl of this system
stward of the sea of Okhotsk, passing through the
south-westerly course to the Yellow Sea.

sun is south of the equator, the great ellipsoidal
e greater distance of their motive projections be-
al equator and the north pole causes these systems
nearly circular. In this case the complementary
he great systems shown *a, a'* Fig. 168 become neces-
l it is possible that the north-western monsoons of
engendered by the complementary whirl between
ting of the Pacific and Atlantic systems, as well as
n of the Indian Ocean now forming a separate
ystem.

terspace whirls to the north of the Atlantic hirl systems.

s discussed which produce complementary whirls regularly constant although weaker. This rotary system would be established, subject only to displacement by certain seasonal influences.

b. The direct impingement of the two ellipsoidal systems in the northern hemisphere suffering restraint at about the 80th parallel, would engender by tangential forces over the entire polar region a constant rotation of this area, producing a constant circumscribing westerly wind around the north pole. Such a system would produce a considerable minus barometrical pressure by tangential action near the pole, and if held constantly without interfering causes would render the inner polar region one of such intense cold in winter as we have no conception of on the globe, as equatorial currents would thereby be entirely shut off, and the polar area be subject to radiation forces at all times in a bright and almost perfectly dry atmosphere.

c. The like conditions occur in the southern polar regions, but in this case as the circumscribing area is less frictional, the tangential forces are therefore more active, and this region becomes one of lower pressure and I have no doubt of more intense cold.

146. Interior whirl systems caused by indraught of aerial currents over continental areas.

a. Following the condition of indraught previously briefly mentioned, art. 134, we have, besides the general agencies of the radiation of heat from the sun and the earth, in the equatorial and polar systems discussed, in composition with those forces, local air and vapour systems over every large terrestrial and aqueous area, where similar agencies to those previously considered are active, according to the powers of radiation the selected area may possess. In such areas the radiational forces will be very different in the separate cases, whether the surface be largely covered by land or by water, the land being a very bad conductor of heat although a very rapid radiant; whereas the liquid areas are to a certain extent absorbent of heat rays; further by the mobility of the liquid system and its general constant motion, the radiation heat-forces are distributed in a short space of time with considerable uniformity (136 art.).

b. If we take the conditions of large continental areas, we find that radiational forces materially influence the general directive motions of aerial currents. The most striking case of this kind is that of the large continental area of Europe and Asia already this immense area the difference of radiational expansions and contractions of the air, induced by uity of the earth's axis, and thereby by the sun's in- nt seasons of the year, represent in these expansions through the changes of temperature, immense forces, placement of a large quantity of aerial gravitating the general equilibrium of elastic forces in the uni- the atmosphere. These forces, at periods of greatest , overpower locally established average surrounding s, and naturally deflect the direct currents of the ystems I have just discussed as equatorial and polar we may find in the central area of the circumscrib- n proposed for Europe and Asia, that air is being is entire area, by contraction from the superior heat earth, at the decline of the year, which indraught ntral Siberia until January, or until we have the sphere represented by 30·4 inches of mercury per t the return of spring, by increased elasticity in the ir is pressed outwards, until in June and July we , or about 62 *lbs. per square foot* less weight of bove this central radiation area. This is quite he vapour system, which upon production, replaces titutes a very large portion of the elastic gravitating *d.* As similar conditions hold largely for both contractions and expansions of aerial systems, it will be convenient for simplicity to take one of these only, and the most convenient will be that of *indraught*, which takes place in any continental area at the decline of the year, or after the sun has passed the summer solstice at the locality taken.

e. The amount of supply to any internal area of contraction is proportional to the forces of minus pressure over the extent of the area taken; such minus pressure giving directive impulse to the area of plus pressure upon all sides. But there being, as I have suggested, in most areas exterior currents already established, the indraught will be taken with greater facility from any exterior projectile aerial system whose impulse is most directed towards the axis of indraught.

f. In such supply currents, although the forces act directly as all compressions and condensations do, they must nevertheless in moving in currents upon local resistances take whirl forms, or make rolling contact upon the lateral inert fluid masses, as a necessity of fluid projection in any form whatever, upon principles already discussed.

g. If we follow the same direction as previously proposed for aerial currents illustrated in Fig. 168, page 401; the most direct course to the Asiatic interior would be by the Arctic seas when such seas were open. This therefore points the direction of currents in autumn when the thermal forces are most active in the northern hemisphere, but the supply currents of the interior of Asia are required in the winter also when these arctic areas are closed by ice, and the ellipsoidal system becomes more circular and somewhat displaced southward.

h. In the general circumscribing aerial ellipsoidal system illustrated, Fig. 168, I could take no conditions of internal circulation; it is nevertheless quite certain that such exists if only under the directive influences of oceanic currents, and it is quite clear also that an internal radiational district of contraction would attain supply from such an internal motive system with equal or greater facility than from an external one whose forces would be directed tangentially more powerfully from the central position taken. In this manner the aerial forces assumed to accompany the great North Atlantic equatorial *oceanic* whirl would carry impulses more directly into the interior of Europe and Asia than that of the

dal system that I have proposed to extend its direct
r north as the Arctic Ocean.

these premises, if we now take into consideration
forces towards this interior Asiatic area, we find
l aerial direction is ruled largely by the eastern
lse of the globe in its minus velocity to deflected equa-
known to exist over central oceanic currents of the
isted by the carrying influences of the oceanic system
npulse is towards the coast of Spain; so that it
suggestive, assuming tangential forces thrown off
whirls, that the Mediterranean area following the
ck and Caspian Seas, would be one most open for a
o the contractile area, of the entire inner circulatory
the interior area of Europe and Asia at the decline
t this as all other courses would be subject to certain
ns of resistance that such currents may encounter
reas over which the current must pass. When we
nditions to which the direction of forces proposed
subject, we find that in this proposed course, cur-
counter considerable land resistance, which would
ct the direction of impulse which the favourable
liquid areas would otherwise offer. In this case in
ction overland in the Mediterranean area, we should

of the great whirl proposed for the aqueous system of this ocean directing its currents somewhat northward of the coast of Spain; that the point of Cape Finistère supports a cone of impression, which, as before discussed, deflects, the flowing forces right and left. Supposing this conic area to be one of pressure also to the aerial system, under the influence of the oceanic carrying force to the atmosphere above, then so far as this carrying influence of the oceanic surface could direct it, by aerial deflections northward of this conic area over the directing oceanic lines, the assumed currents would gain easterly momentum by the minus latitude velocity of the earth. So that in the northerly direction possibly, there would be the most direct impulse to establish supply currents to the internal area proposed.

k. We may now consider the conditions we have taken of the direction of the oceanic system which by the influence of central momentum of the N. Atlantic, may be assumed to project a tangential current in a north-easterly direction, that is, towards the Baltic. There appears to be present many conditions which favour this course of aerial supply by a moderately frictionless course in the autumn and winter when it is required by aerial conditions of condensation from terrestrial radiation.

l. This course, in the first place, is only a little more northerly than the aerial deflection I assume over Cape Finistère in Spain, so that a direct impulse is given by the winds of the North Atlantic equatorial system to move in a more northerly direction. Therefore in this direction a moderately frictionless course is opened by the English Channel, and the low-lying countries of Holland, and Northern Prussia, as the most free area; deflecting possibly a part of the indraught as far north as the Gulf of Finland, Lake Ladoga, and Lake Onega. Here passing by moderately level ground as far as the Ural Mountains, which are really to this course the only serious land impediment. But these mountains are for the most part undulatory with many easy passes, so that the greatest resistance that they effect is only such as will cause lower supply currents to be deflected upward and therefore supply largely by a system of overflow. The above therefore seems altogether the most probable means of supply currents to the large interior areas of Europe and Asia under aerial contraction, and this course appears to be consistent with the excellent maps of Mr. A. Buchan in his important paper previously referred to. A deflection of the surface currents being observable in these maps in front of the Ural Mountains.

ltic system, assuming the causes given sufficient to rrents proposed, these currents could only enter the tion by lateral whirls making rolling contact upon aerial fluids present, which fact appears to be gener- with observations of the prevailing winds. But it ortant to observe that such currents would produce nt of a system of aerial motion, and this would be previously discussed for Arctic currents, acting on the aerial resistances, and inducing a form of that could be reversed only by a frictional mode efore such a supply current, although oscillatory, or eversed at times, within the elasticity of the system, or less constant even after the forces that caused ased to act. Therefore the first effects of expansions ing would, under this projection, open out for them- tional channel in some other direction rather than blished currents.

e whole matter of European and Asiatic projection uses given, it follows that the internal contraction of the aerial fluids in this great continental area nternal whirl system which is continuous with the our systems proposed, following approximately

CHAPTER XIII.

DIRECTION OF CURRENTS DERIVED FROM VERTICAL MOVEMENTS OF WATER PRODUCED BY THERMAL CAUSES. DEFLECTIONS UNDER RESISTANCE BY WHICH VERTICAL CURRENTS OVERFLOW AND UNDERFLOW. COMPOSITIONS WITH REVOLUTION VELOCITIES OF THE GLOBE. OBLIQUE WHIRL SYSTEMS. TIDAL INFLUENCES.

147. Vertical Oceanic Circulation.

a. The motive principles of vertical circulation have already been partly discussed as effects of thermal forces, articles 112, 113, and 116. I now propose to take certain conditions of local effects which may be rendered somewhat evident in the actual motions of oceanic currents.

b. To the motive forces of the air alone in winds Sir John Herschel attributed the entire motion of the ocean, not only for waves, but for currents. Dr. Carpenter by his researches in deep-sea soundings has shown that the oceanic surface currents which flow fairly in the direction of the wind, where this is constant, may be of very inconsiderable depth; underflowing currents taking most frequently an entirely opposite direction to surface drifts. Upon the accurate observations made of these facts, I think that Dr. Carpenter has fully assured us that oceanic circulation exists entirely independent of aerial movements. The principle of this important physical law appears to have been made out, as before mentioned, by Professor Lenz of St. Petersburg, by demonstrations obtained in the voyage of the *Kotzebue* 1825 to 1828, from which he first showed by temperature soundings that there must be a constant inflow of heavy polar water to the tropics, and an equal overflow of the lighter heated surface waters therefrom. This important theory he propounded in 1845 but it met the usual fate of nearly all great theories, that it clashed too much with preconceived ideas educationally

accepted, or even examined; until the entirely new
r. Carpenter in the voyage of the *Challenger* in 1868
v grounds, the entire theory of Lenz. It is now
to careful observers that polar undercurrents must
ator, as polar water, by the evidence of temperature,
undings at much less depth at the equator than in
titudes. It is further evident that such inflow in
necessary to restore the equilibrium of projection
areas, which is observable in the directions of large
s, such as in that of the Gulf Stream. These under-
also active in supplying the loss from excessive eva-
the tropical oceanic surface and therefore so far in
erflow.

lower inflow towards the equator is evidently of
as been further assured negatively, by sounding in
om polar currents by the oceanic entrance of such
less depth; in which case, there is no low deep-
e in undercurrents. This we find demonstrated by
igh temperatures of the Mediterranean and Red
depths. Further underflowing polar currents have
Dr. Carpenter from near the polar region without
the tropical. On the other hand, the overflowing
e N. Atlantic Ocean particularly have been clearly

conceive that there is some source of radiant heat above the water surface that has power to penetrate the water and to expand it in some proportion to depth, for a certain depth, which the heat force can penetrate. Then if the heat-force were distributed equally over the entire oceanic surface, the result would be only, that after a certain time the whole of the water would remain in vertical density equilibrium, the coldest or densest stratum being at the bottom, and less dense strata consecutively above up to the surface, where the heat is assumed to be most intense.

e. If we now imagine such a system as that given above to be established over oceanic areas, and that we change the conditions by placing the source of heat in such a position that it can act upon one *end* of the aqueous system only; then in this case it is quite clear that the expansile force that rendered the water less dense would be active at this part only, and that, supposing the heat upon the whole the same as that at first proposed for distribution over the surface, the heated part would be most expanded by the local concentration of the heat-forces.

f. If we now imagine that another portion of the same liquid system at some distance from the first is open to space but shaded from the given source of heat, then by the law of interchanges of heat established by Prevost, this shaded area would become that of the greatest radiation of its own heat; so that it would quickly lose its initial heat and become as cold and dense at the surface as at a depth taken for the constant temperature of the lower water. Further, the dense surface water, cooled by radiation, sinking to gravitation equilibrium of its density in relation to the water immediately beneath it, would replace this less dense water until the whole system over the source of surface self-radiation became one of equally cold dense mass. Now if such heat expansion and cold contraction remained immobile, we must have after a time, a division vertically in the fluid system in which a light and a dense fluid would rest vertically, against each other. This it is quite clear, by laws well understood in hydrodynamics, would be impossible, but what would occur is that we should have through the action of gravitation forces present, the parts of the fluid constantly moving to a state of density equilibrium, as we observe actually in the system pursued in the heating of buildings by water.

g. It is clear that the above conditions are those that actually exist in the oceanic system between equatorial and polar regions;

density gravitation equilibrium, in equation with the
-force, is distributed by the differences of densit;
on the forces of local radiation of the sun upon the
the earth into space, as previously discussed. Upon
les we find that gravitation acts as a constant force
ndently of other forces; this force being active to
onditions of density equilibrium in the general fluid
uently the aqueous system becomes motive, the colder
underflowing constantly to gravitation equilibrium,
er less dense water *overflowing* to re-establish surface
In such motion, however, the direction which currents
ke to avoid the resistances of frictional surface will
modify this simple condition, taken *per se*, as I will
eavour to show.

stem of overflowing and underflowing currents as
eanic areas is graphically represented by an experi-
Carpenter, as shown in the diagram below. In which
glass sides is filled with water at the temperature of
eated body, formed of a hollow vessel in which steam
represent the action of the sun's rays, is placed over
he trough, and a block of ice is placed at the other.
fter, currents are induced, which are made apparent in

we have no solid boundary in the ocean representable by the end of the trough. But in this matter we can conceive that the polar ice, which is of considerable depth, will represent sufficient resistance for the cold end of the system, and the oppositely directed underflow from the north and south circumpolar regions will terminate this projection near the equator or where these polar forces meet, and oppose each other, and thereby represent the heated end of the trough. Some further conditions of which I will consider, on principles of whirl-motion, hereafter.

148. Influence of the solid surface of the land upon open oceanic systems. Midcurrents.

a. By the conditions discussed in the fourth chapter, the resting surface upon which a fluid moves, will be sufficiently frictional to the fluid to ensure motions of rolling contact of its parts. Now, assuming the actions of thermal forces in water to produce displacements in overcurrents in one direction, and undercurrents in compensation to move the water in the opposite direction. The undercurrents assumed to be of the greater density by temperature must then move upon or near the resting surface of land in a very close system, and such a motion would be very frictional. But if we take these motions to be active in a liquid system of great depth, and assume an undercurrent necessary either as a compensating current or otherwise to thermal effects, it is in no way necessary that this should extend to the *entire depth of the system*, as it is quite evident that motion in an intermediate depth, as being more distant from the resting surface, would be less frictional. Therefore it becomes extremely probable that an undercurrent in deep water, or other fluid, will have a constant tendency to take a middle or intermediate course where the resistances from the upper current flowing in an opposite direction, and the friction of land surface are brought in equilibrium about the axis of projection. Upon these premises it is very possible that active undercurrents in the ocean do not extend to the land surface in deep water, but that they flow in intermediate space, leaving the land surface in almost perfect repose.

b. Under the above conditions the rolling contact of an oceanic undercurrent, or as it would be really, as now proposed, a *midcurrent*, would deflect waters upwards and downwards, therefore move on biwhirl principles. The evidence of such form of projec-

nd in 77 and 81 props., except that the influence
t taken in the latter proposition. This is, however,
op. *b*, but here we lose some of the conditions of
rl projection, as the resultant of continuity of like
.

ter is important it may be well to refer again to ex-
w the possibility of such a form of motion as may
urrent in a very deep fluid, in the projection of upper
s, although the experiment I shall propose will not
the conditions of a varying density system.
a tea-chest as in Prof. Tait's experiment, 66 prop. *e*,
overing the open top with a light canvas we fix the
he top so as to form what is known technically as
may then project a current of ammonia chloride as
ermittently or constantly for the motive extent of the
If we further, instead of making a circular hole in
chest as before described, make an open slit entirely
y then readily project a flat horizontal current. In
urrent will flow upwards and downwards by projec-
esistant air in equilibrium, and resemble in its pro-
urrent, making rolling contact in upper and lower

less than 200 fathoms in latitudes 38° north and south but about 600 fathoms at the equator. By the above I imagine that the axis of undercurrent motion is in about 39° Fahr. or perhaps more nearly 38°·6. The temperature depths above and below this appear to spread out generally in opposite directions extending north and south, particularly from the tropics to the equator.

f. I have taken the following diagram from one given in Dr. Carpenter's paper before referred to, but here drawn to a smaller horizontal scale. Midcurrent whirls being indicated at about the position I assume that they may occur. The depth of the whirls will, however, vary with the longitude from other causes, the motive system being by composition with revolution velocities in oblique plane, of which the diagram only theoretically represents a vertical section. Secondary biwhirls possibly form at the surface exterior to lat. 20° north and south, which are indicated in the engraving.

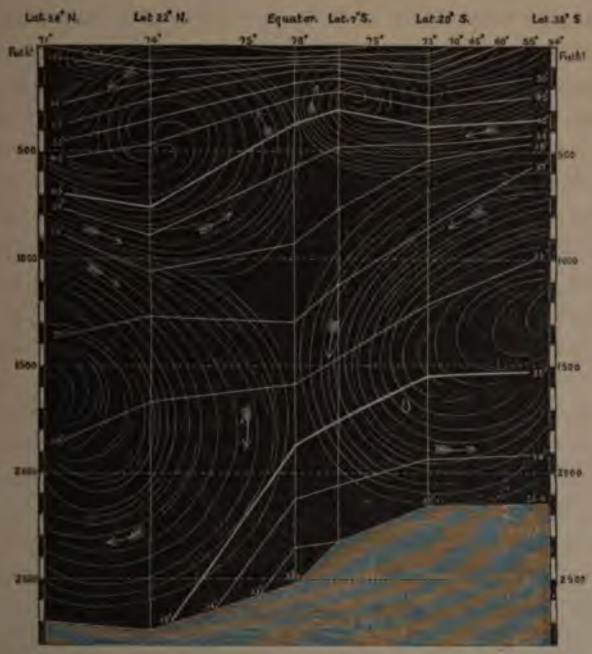

Fig. 172.—Diagram—Oceanic Section through the Atlantic showing Temperature Depths from Dr. Carpenter. The fine curved lines showing Vertical Elements of the Whirl System I propose.

149. Overflowing Forces caused by deflection from conic resistance. Vertical whirl force in oceanic currents.

a. If we duplicate the whirl system shown in Dr. Carpenter's experiment on each side of the equator, as before suggested, we shall have in the denser lower water a certain volume approaching by undercurrents towards the regions of heat of the thermal equator of the season, and have expanded and lighter overflowing and outflowing currents above on each side of the same region. The projectile properties of such flowing forces of matter, carrying momentum proportional to their masses into their velocities, we cannot imagine to come to rest after projection without maintaining an impulse as the momentum, deducting only the friction of contact on contiguous parts. Now I have assumed that fluids moving by their own velocities of greatest accommodation, as in a liquid system returning to gravitation equilibrium, suffer very small loss by friction; so that in this case the projectile momentum is largely conserved, and although the actual motion of translation may be conceived to be very slow, the masses affected in an oceanic system are very large, and the forces are effectively duplicated by opposition to each other, so that the entire momentum in collision is as great, or nearly so, as the united forces from which it is derived.

b. By the principles of whirl motions that I have endeavoured to demonstrate in many propositions, fluid projections are shown to be never perfectly resisted within any fluid system, the forces being conserved by deflections from the resistances, to move into the least frictional paths. Therefore in this case, if we have two density underflowing currents of cold polar water directed upon each other towards the equatorial area moving with any force whatever, small or large, the united forces will not directly oppose each other as perfect resistances, but they will both be *deflected* to the spaces offering the least resistance.

c. In the case given above it is not difficult to discover the area of least resistance, as the opposing currents cannot be deflected far towards the solid earth on which the water rests, nor laterally without encountering equal resistances from other approaching parts. They must therefore be deflected *upwards;* so that we may imagine a certain area at the oceanic lower surface to remain static by compression from the opposing flowing forces on each side of the equator, and this static mass to form a cone of resistance to the flowing forces that will themselves, by the momentum they carry, deflect the opposing direct currents upwards as whirls, over the cone of impression the one flowing force forms to the other; as in all other cases of fluid projection of which I have given many instances.

d. It is quite clear that the overflowing surface expansile systems would thus be forces that would enter into motive composition with whirls projected from the lower inflowing system, and complete the whirl system in underflowing and overflowing currents, in which both parts would be active, subject to certain conditions of friction upon the resting surface, discussed in the last article.

e. By the above principles we have movements of liquids upon the globe that maintain certain positions, which we may denominate forces of *cold*, engendering northern and southern underflowing currents constantly flowing towards the thermal equator; and we have equal expansile currents, which we may denominate *heat* forces, overflowing from the equator; in both instances directed to restore the density equilibrium disturbed by the forces of *radiation* from the sun upon one part of the globe, and from the earth in another. The momentum of underflowing forces being conserved by deflection at the meeting line which occurs at the region of greatest intensity of the expansile heat-forces. The general principles of the above may be represented by the following diagram, where A represents the thermal equator for the time being; C the conic area of resistance, formed by static water resting on the bottom of the ocean, or upon any deep motive plane that may represent the extent of whirl circulation for the stratum taken.

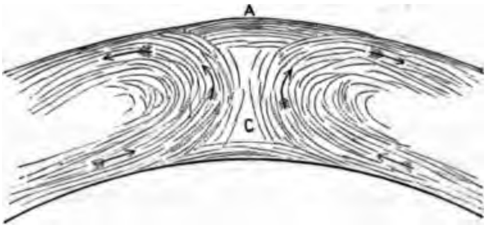

Fig. 173.—Diagram of Equatorial Oceanic Whirls.

f. It will be seen in this system that a secondary cone of resistance to the rotary incipient whirl systems right and left is formed by the upturned momentum of the deflected undercurrent force under A. This remains in the equatorial system as a band of still water, and the overflowing forces commence at some distance from this, where the incipient whirls may nearly reach the surface.

erally be conceived that the above conditions relate vation for overflow of parts of the aqueous system y the density of parts quite reach the surface to form nt, or to the greatest depth to form a lower current. rflow approach *near* the surface it will act as a rata above.

projectile forces by the impulses derived from thermal before discussed for another case, would not be ny imaginable single effort of thermal force; but by ntinuity of efforts of separate units of motive force vely together, with the almost frictionless modes of ds follow at velocities capable of the greatest accom- system becomes finally in a certain condition of quilibrium.

on motive system acting by local thermal densities, rces may be separately considered as small, may, est accommodation that is possible in fluid matter, o the continuity of motion of a massive wheel perfect axis which maintains a large mass of gravi- n motion by small constantly intermittent impulses of its motion, although it would at first require rce, or a long continuity of smaller impulses, to pro-a *force*, the influence of the wind represents only another *force*, which enters into composition with it, and deflects the fluid affected to the area of least resistance under the composition of all forces present. In this manner the expansive overflow acting as regards thermal effects only as a force directing the surface water directly from the equator to the tropic with small loss of revolution momentum, and the trade-winds moving directly towards the tropic, with a strong minus latitude momentum, gives by composition a westernly drift, the opposite polar and equatorial momentum of the two forces being apparently suppressed at the surface. Upon the above principles the united momentum of overflowing oceanic and wind forces conspire to produce one area of elevation or directive force upon the western sides of the oceanic areas near the thermal equator. This action is clearly auxiliary to the forces considered, 115 art., for revolution momentum of matter newly arriving at the equatorial zone, and modifies by composition the conditions of vertical circulation considerably.

151. Influence of Latitudinal Revolution velocity on vertical systems of displacement in equatorial oceanic systems producing oblique planes of motion.

a. I have discussed the principles of the action of revolution velocity upon oceanic surface systems for horizontal currents, 115 art. It remains now to consider some conditions which particularly relate to the direction of undercurrents whose force lines take the place of compensating systems, by their moving in the opposite direction to overcurrents, their directions being outward from the polar regions, as the thermal surface currents are inward.

b. The heavy cold water as it is projected as an undercurrent from polar regions towards the equator, in moving to gravitation equilibrium in equation with its density, carries a constant minus revolution velocity to the latitude of the earth it reaches, as before stated, therefore, it constantly drifts towards the *western borders* of the oceanic basins; whereas the overflowing surface waters moving with plus revolution velocity were shown, 128 art. *i*, *j*, to drift towards the *eastern borders*, this we may take as a general principle. Therefore these drifting undercurrents have motive direction towards the very points of the oceanic system where the direction of the trade-winds, and with them the surface waters are mostly drifted, that is to the same western sides of the oceanic basins.

pulse of these currents meet opposing resistances,
onserve their momentum, suffer deflection, which is
the path of least resistance, as before stated. In this
e Northern Atlantic system, the polar minus revolu-
carries the cold dense polar water projected south-
ercurrent to westward along the coast of Greenland,
cts its impulse upon the Greenland coast and on-
he mouth of Davis' Strait; but here the current
onal resistance of the outflowing waters issuing from
ida coast by causes already discussed (128 art.), so
ite impulses deflect such meeting currents directly
direction across the Atlantic, the westerly direction
eing blocked by land; at the same time the deflected
s they can absolutely meet, engender such a com-
resistance, that the polar currents are thrown off the
in every direction that does not perfectly oppose the
rved elastic force of the currents they meet from the

eady discussed the conditions under which overcur-
certain oceanic districts, in which they maintain a
of radiation of heat into the circumpolar atmosphere
ss as would convert them into descending cold cur-

ing the western shores of Spain, France, the British Isles, and the coast of Norway are bathed by warm currents by causes discussed, and that the directly opposite shores near the coast of Newfoundland, Labrador, and Greenland are bathed with cold currents; and for the most part loaded constantly with ice. Now, as regards these opposite positions, by thermal gravitation effects simply, the underflowing currents are directed from the one position to the other in proportion to the differences of temperature density of the water according to well established laws for fluid forces known as a principle of hydrodynamics, and made use of practically in heating buildings by hot water. The effect of the surface extension of cold undercurrent water towards western borders of the basins, by the above causes, permits dense cold water to flow in continuous volume towards the temperate areas, and the lighter thermal equatorial currents to flow into the polar oceans by the eastern sides by continuous circulation. The direction of underflowing dense currents and overflowing lighter warmer currents under actual conditions, as in the regions of the Gulf Stream, are therefore compelled to cross each other in superposition at a certain point in equation with the directive forces derived from thermal causes into revolution velocities simply.

e. As overflowing currents, moving by direct thermal effects, take directions which are most free from land in the North Atlantic, or any other area, and such directions are also mostly under the influence of the motive force of the wind established by other causes, already considered, these overcurrents generally tend to establish the actual direction of surface forces, as before proposed, to the influence of which the undercurrents may be considered to act as complementary in order to complete a circulatory system.

f. Taking the above conditions for the whole of the Northern Atlantic area, beginning at the cold or greatest density projection, we find a cold undercurrent from the polar regions constantly flowing southward past the icebound coast of Greenland, Davis' Straits, and the coast of Labrador, and the same current then underflowing onwards by its density in an easterly direction in the same latitude. It therefore underflows the area of the Gulf Stream, carrying its density momentum across the Atlantic nearly to the coast of Africa, where it is possibly projected upwards, and laterally, by the deflection of its direct momentum against the resistance of the coast, here gradually, being warmed by the sun's rays it enters the surface in what may now be considered as a compensating system to the northern polar projection; and appears to be further deflected in rising as a surface current by the trade-winds in composition with its own direct impulse. In this general course now proceeding westerly near the equator it appears to continue until it is again deflected by the eastern coast of America. We may assume that near the equator, having its temperature raised by its less dense heated waters, it now overflows its previous direction in the Gulf Stream or general north-eastern drift, where its direct impulse is further carried onwards into high polar latitudes to become cooled down by radiation into space, so as again to enter its previous course drifting along in the Greenland current until it falls once more in the course of projection as an undercurrent off the coast of Newfoundland.

It is not necessary in the above sketch to suppose, although this may be the general drift of the aqueous forces discussed, that it is absolutely the same portion of water that passes through the entire course depicted, this is quite improbable, although possible for the course of any single particle. It is clear that any part of the system may be evaporated at the tropics, or left frozen near the poles, or be deflected from the course pointed out; but in this case other motive water takes up the forces lost by transference of impulse.

g. The following diagram will show by the arrows the principles here discussed, the underflowing and overflowing forces forming the figure 8 for a certain limit of circulation.

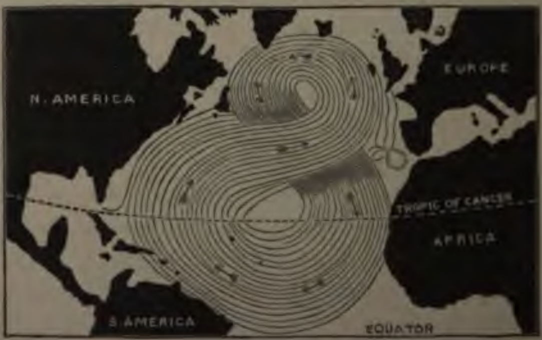

Fig. 174.—Diagram—Undercurrent, North Atlantic System.

h. It may be observed that this system in no way interferes with that proposed, 115 art., for horizontal circulation, which as a superimposed system, may be complete. It really forms a part of the same system of motive forces that could not be entered into at the time, or until further principles were discussed. These undercurrent directions of density systems may be taken in composition with surface whirl systems; such undercurrent systems very generally attaining directive forces, through which the same systematic whirls are engendered in the lower stratum, as were previously discussed for the upper ones; so that the figure eight only represents the direction of a certain axis of *biwhirl* deflection, forming in both areas of the two loops of the figure a complete whirl *in another plane* of motion; by the force of which a part of the water, in this case of the N. Atlantic system of the northern whirl, will be thrown into the more southern system, and a part after deflection on a cone of resistance which occurs at about the coast of Portugal, for some portion of the current, back into its own whirl system. This could not be shown in the engraving without complication. In this diagram I have taken a certain plane in two whirls only, but the same system no doubt in my mind extends to currents upward into the extreme northern regions by similar deflections which, taken separately, would form the like figure for certain current lines.

i. Again the undercurrent here proposed, leaving the Newfoundland coast projected in its axis in an easterly course as a density current, would at its southern borders be deflected southward to form not only the circumferential parts of an undercurrent whirl extending near to the equator, but would also fill by whirl deflection the entire centre of the system, so that this *infusion*, if I may so term it, added to the minus revolution velocity it experiences in moving southwards, again deflects a part of the force westward, causing the entire polar current to be deflected over nearly every part of the Atlantic towards the equator with some part of its force, the axis of direction only being in the lines proposed, in the last figure.

j. Further, the undercurrent motive system, being active upon similar principles to the upper system, it must follow lines similar to those discussed in 128 art. for the Gulf Stream. Thus there is in the undercurrents probably a considerable conic bifurcation off the Newfoundland coast, another off the African coast, sending a deflection to the Straits of Gibraltar, and another further south, sending a deflection from Cape Verde into the South Atlantic. This last possibly acting as a compensating current to the western ection, of which a part ultimately forms the Gulf

ceanic system we have two elements of motion
project currents in a westerly direction:—That of the
impulse active upon all waters arriving by any cause
lar areas towards the equator, which are either de-
s by opposite equatorial resistance, or in polar under-
ssing a certain motive energy, or carrying force upon
and we have the impulse of underflowing aerial cur-
pon the oceanic surface in the same direction. The
drift by cumulative impulses from these causes being
s it reaches western boundaries, so that we find that
keep widely apart and flow gently by horizontal
art. *i*), on the eastern tropical oceanic areas are
ensed by convergence of impulse upon the western
rrents are most active. This occurs in the Atlantic,
dian Oceans.

of the above conditions are naturally subject to
s from the positions of land and oceanic depths. So
forces, upon principles discussed, whirl and biwhirl
oceanic systems generally take certain elements of
her, an equatorial projection falling obliquely against

axis of inertia, 124 art. *c*, there will at all times be a tendency in currents to maintain the same areas of projection, they will also tend to wear out the deep channels, the section of which will constantly approach a semicircle, except that the tangential force of whirl currents will always throw the axis of the current outward, so that the section from the centre will be actually more nearly pear-shaped, as shown in the diagram below.

Fig. 175.—Diagram—Theoretical Section of an Oceanic Basin showing ultimate effects of Whirl Action.

152. Influence of the Sun and Moon in Tidal Phenomena in constantly restoring Gravitation Equilibrium.

If we imagine a fluid projection engendered by thermal expansion, condensation, evaporation, rainfall, and revolution impulse to proceed from polar to equatorial regions to establish gravitation equilibrium between a couple of forces, we can at once see that such motions, within the velocities of perfect fluid accommodation of the least frictional form, must be very slow. But we have in the intermittent attractions of the sun and moon constant separate efforts of local superior motive force, which at each effort raises a certain mass of water above the point of mean static equilibrium; and although this force is diurnal and intermittent, it is superior in immediate effect to thermal and evaporative forces, therefore it moves the liquid mass at every effort beyond the plane of equal mean gravitation equilibrium, leaving it when the attractive force is withdrawn to fall to the natural gravitation equilibrium of the system. By this means, of oscillation beyond the point of mean equilibrium, every force out of equilibrium in an extensive fluid mass is *accelerated in its direction towards the equilibrium which is constantly being only partially restored*, so that we may add tidal forces, which act cumulatively, to other modes of motion which I have offered as being active to accelerate the motive impulses previously considered in restoring equilibrium, and thereby rendering such *permanently* active in their motive directions by composition with all forces present in actual fluid systems.

CHAPTER XIV.

IWHIRL SYSTEMS OF VERTICAL CIRCULATION IN
OSPHERE — COMPOSITION WITH HORIZONTAL SYS-
LIQUE SYSTEMS—CYCLONES—HURRICANES—ANTI-
—CLIMATIC INFLUENCES.

l principles of vertical aerial circulation.

rs to me somewhat curious that Sir John Herschel,
ived Lenz's theory of under and overflow of oceanic
ced by thermal causes, should have himself proposed
similar theory for the under and overflow of aerial
has done in art. 52 of his "Physical Geography" in
ion of the *Encyclopedia Britannica*. In this he offers

therefore there will be a great expansion of aerial fluids; at the poles very little (112 art. *e*).

d. As before stated, the influences of equatorial expansions cause the air near the equator to have less specific density, and the constant excess of radiation of heat near the poles produces greater specific density, the air being held to the surface of the earth by the attractive force of gravitation, acting with greatest intensity on the colder, more condensed, and nearer parts of the air, which parts are therefore urged to flow at all points to an equal surface of gravitation density. The warmer, lighter, or more expanded air, in this manner, receives less gravitative impulse, and takes its position above the heavier fluid in the same manner as air takes its position by gravitation above water. This it does in proportion to its motile force, or power of accommodation for one part of the system to displace the other, that this arrangement may occur.

e. Now it is apparent that the above-mentioned systems of forces must be active in the manner described, but as terrestrial currents do not entirely follow such directions as here implied, of simple density superposition, we may conclude that as we have taken fluid force to be persistent, that there are modifying causes which deflect aerial currents into the directions we find them by observation.

f. To follow this matter into the principles by which aerial matter is projected upwards in certain regions of the earth, we find that the sun's heat is equally active over nearly the whole of the broad tropical band, where the sun's meridian altitude is never less than 66½ degrees. Therefore in these tropical regions the most material expansions of the air take place, thereby forming upward currents of great breadth which can have only a limited projection against gravitation before being thrown out of equilibrium to the general gravitative system of the globe, and hence they must overflow in order to continue the vertical thermal projection caused by heat expansions, as before proposed. In this case there must also be an equal inflow of air to the overflow, for the atmospheric pressure to remain nearly constant as we actually observe it does, and this must occur, as before stated, by undercurrents, which extend to the equatorial band of upward draught. As auxiliary to the direction of this inflow, we have also, by the aerial friction upon the oceanic surface, a region of induced oceanic surface movements, which I have shown are influenced to flow in the same direction as the aerial, and which, by reaction, consequently establish a consistency of

erial inflow in the least frictional course. The aqueous
es by cumulative efforts being throughout the system
ch other's motion in the directions of flowing forces,
ordance with the above we have in similar positions
e a like direction of active aqueous and aerial forces
frictional surfaces, observable, for inflow particularly,
of the trade-winds, which by the causes given, may
accounted for.

ishment of the vertical aerial whirl system of

w take the trade-winds flowing from their origin
r areas towards equatorial ones, as equal systems
e entire equatorial regions, and consider the equatorial
rces, without for the present taking into account the
ion brought about by the difference of circumferential
parts of the earth or the kind of surface over which
ss, we have then a similar case to that discussed for
s (149 art.); that is, two fluid forces flowing from
southern polar areas in direct opposition to each
near the seasonal heat zone; and we may at this
again look for similar results to those discussed for

velocity, the whole momentum of the system would be deflected by the entire resistance in one path only, that is, *upwards*.

c. I have supposed in the above case of two opposing systems of flowing air to the equator, that absolute contact is made between them, but if we analyse the possible conditions we see at once that this is impossible, or only possible, for an infinitely thin stream of opposing flowing fluid. In the first place, for the meeting in one area of two volumes of air there must be space for the air contained in the two currents, which press against each other, and, as air is an elastic fluid, the meeting currents would form a *volume of condensed air*, which assuming the forces equal would immediately produce by reaction a broad band wherein the air brought to equilibrium would rest static. Further, after this, any inflowing equal current moving upon this static band would increase its breadth and therefore its resistance; so that the band would finally represent a broad static mass of condensed air, which would be sufficiently extensive from its inertia alone to form a resistance to any future approaching flowing aerial fluid. We may further conceive that the influence of this central resistance would be perceptible in the approaching air so far as the elastic reaction of the condensation could act.

d. We find in consideration of further conditions that the trade-winds do not consist of a narrow band of matter, but of a constant stream of large volume; consequently, although we may imagine a small portion of the trade-winds to reach the point of resistance just described, the larger part could in no way reach this point. Now, by the laws of flowing force fully discussed, a fluid will uniformly flow to the points of least resistance, and as I have shown that the opposite flowing currents are resisted at all points but one, we must conclude that the *whole of the flowing force* so far as the equatorial or thermal directions of its momentum is conserved, will be directed upwards, as before discussed.

e. Taking at this point of our theory two flowing fluids brought to a plane of resistance and deflected upwards, we may follow the components of force-direction necessarily engendered thereby. The first impulse of the resisted elastic fluid being directed upwards, from both sides of the heat zone, there would be elevated a volume of air and vapour, but we cannot imagine that this would be raised to an *unlimited* height; for after the elevation of a certain volume of the flowing mass, the weight of this mass alone would after-a pressure upon the rising current, so that as the atmosphere was constantly elevated it would form sistance to further elevation, and would finally have omentum superior to gravitation. Therefore as it rds it would be brought at a certain altitude to a

further conceive from the atmosphere being elastic it rises it is constantly expanding by the minus surures and its power of elastic extensibility (4 prop. *c*), s expansion it overcomes the resistance of the sural matter, and at a certain elevated position, when to a state of vertical equilibrium, it rests upon the elow as a pressure of static mass, in a similar manner the oppositely directed horizontal forces, just menhe inflowing currents from north and south to equili- equator at the surface of the globe.

seen by the causes offered above, that we have finally or a mass of quiescent aerial matter whose inertia he flowing force of currents by compression upon its In this we have not a mere plane of resistance at oint, but an extensive *volume* which becomes in a equilibrium of inertia to the inflowing forces of the thermal zone. Upon this ring-like conoid of resistance, inflowing aerial fluids after deflection at the tropical surface attain a certain altitude, and are again deflected by conic resistance, so that they overflow by a *circuit* from the point of original projection, and induce thereby a circumscribing biwhirl system.

i. Taking the whole of the conditions above given, and assuming any possible inert volume of air laterally contiguous to the directly rising aerial fluids situated outwards from the position of the more active upward thermal projections, such fluids will be affected by adhesion to the rising motive currents acting tangentially upon them as before considered for liquids, 149 art. Therefore if we assume a static volume of air to exist laterally above the undercurrent of flowing force exterior to the heat zone, such a volume will be moved tangentially by the constancy of the undercurrent, it will also be moved in relation to its centre of inertia in the same direction, tangentially, by the constant friction of the upturned deflection of the undercurrent, and in like manner by the constant overflow from causes given, supposing these forces so far to circumscribe the centre of inertia of the lateral mass.

j. Under the above circumstances active in inducing whirl systems by tangential force, of motive parts of the system, whose tangential moments may complete the whirl for an entire circuit by their separate impulses, with such deflections as the many correlative conditions bring about, I will now endeavour to show diagrammatically, by representing the entire phenomena under certain limited conditions.

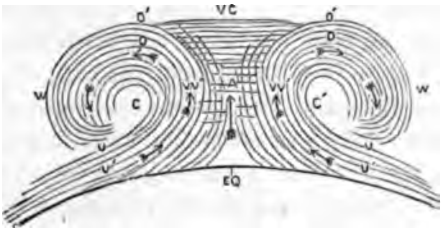

Fig. 176.—Diagram of Aerial Forces active about the Thermal Equator.

E Q. Position of the thermal equator towards which inflowing currents move from circumpolar areas.

U, U' Undercurrents of flowing force having the greatest density and mass velocity at U'U'.

ed undercurrents moving upon the area of greatest
over E Q by which they take vertical direc-

rrents, deflected by the aerial matter raised by verti-
ds V C upward to form a superior cone of resistance;
ction being constant until the matter raised against
action equals the force of projection. The greatest
astic force remaining in continuity of projection at
on the whirl systems induced by the now inward,
erflowing exterior forces.

of inertia to the lateral whirls.

ove scheme I have intentionally left incomplete the
t will be seen that the motive effects offered would
ccount for three sides of such a whirl, but we may
f the circumferential resistance upon the fourth side
d the general resistance of the motive system, that
momentum of the other three sides in moving a
stem upon its centre of inertia will carry the circum-
ntum over the fourth side; there is, however, on the
of the whirl a special form of resistance necessary
d, which is found in that we have in the descending
irl at W, the tangential forces of the motive parts
untering a higher resistance by the greater density

system not entering the whirl, but causing it to extend the overflowing currents possibly into polar regions.

155. Influences of vapour force and condensation upon the equatorial aerial biwhirl system.

a. In reconsidering the action of the expansive force heat, in the terrestrial aqueous vapour system; I have already observed, 117 art., that vapour possesses special functions of vertical lifting force derived from the expansion of water to nearly 1000 times its volume at an average tropical heat and pressure. This vapour may therefore be considered, upon its production, to consist of new matter, which replaces an equal volume of air, as before stated, since we do not find that it is chemically absorbed in any way by the air; for if this were the case, the air would be of greater specific density by the intrusion of vapour, whereas it is really of less.

b. It is very probable, that over oceans the evaporating force varies directly as the verticality of the sun's rays falling upon the surface of water exposed to its direct heating effects, and inversely as the humidity of the air above it. In equatorial regions we may entirely neglect all functions of humidity of the air, as the diathermacy of the atmosphere appears almost entirely to depend upon the deficiency of humidity; so that possibly there will be little difference in entire elastic force derived from the sun's rays, whether the atmosphere be moist, and the sun's heat be retained to expand the moisture or cloud to elastic vapour; or dry, so that it evaporates the surface water directly; as in either case it engenders an elastic aerial system over one area that acts possibly as an equal force of aerial extension in both.

c. The small declination of the sun's rays possible over an equatorial band extending from 10 to 20 degrees, will leave this zone approximately equal throughout, in its vapour-elevating force; the deflection of uprising currents would therefore occur generally before they reach this area of greatest intensity of heat-force by the *volume* of inflow of the lower surface currents. I think from this cause it is extremely probable that the vapour raised within the limits of an equatorial band of about 20 degrees is not deflected considerably to overflow, but that the vapour rises to a point of saturation, and forms a resistance to inflowing currents, being for the most part condensed to water over the *same area* when the vapour pressure exceeds the elastic thermal force of the average om penetration of the sun's heat through it, to the of evaporation beneath. This leaves the position of urrents, *exterior* to the equatorial band proposed of e surface of the globe. The direct lateral impulses, carry the inflowing currents much nearer together ted position, where the earth's superficial resistance lt, so that they may possibly approach at the elevanospheric altitude of projection to within possibly s of each other. Therefore the evaporation taking within the cone of impression V C, Fig. 176, would he earth as rain in the vicinity of its elevation.

ffects of condensation of overflowing vapour.

at derived from the sun is a constant diurnal force, pour retains radiant heat in an exceptional degree slightly diathermous; it is most probable that the sphere in rising in the manner described, will fully lastic force in its vapour system as a perfect gas on under less compression when rising directly in o that no condensation to *cloud* may occur from the g daytime in tropical areas. Now, in the area over there is an overflow, that is, not the tropical area of the elastic forces of air and vapour, we find that the air diminishes in volume in approximately equal ratio for equal loss of heat; whereas on the other hand, the condensation of vapour is nearly instantaneous for such volume of the vapour as may be converted into cloud or water; therefore the loss of elastic force in the vapour system, supposing this to proceed in regular proportion to distance from the thermal equator, would be in a much higher ratio than that of the air, and although the condensation of the vapour would release a certain amount of heat-force which would be communicated to the air to increase its elasticity, yet as the angle of declination of the sun from the thermal *equator* became greater, this force would be constantly lost in a much higher ratio by radiation into space, as before stated.

c. Further, we can imagine that at a certain angle of declination to the thermal equator, the aerial and vaporous system would lose elastic or heat-force and form visible cloud. That at this area the sun's heat being shaded from all lower strata of vaporous air in the same system, that rapid condensation would occur beneath the cloud, the direct influence of the sun's ray being taken from the entire intervening space between cloud and earth; so that, if we imagine some latitude temperature whereupon a cloud-covered area could rest there would be by the causes discussed, here constant condensation into which the sun's rays could not penetrate to preserve the elastic force in the lower stratum of vapour. In such an assumed area of condensation from the immediate minus pressure that the condensation would produce, less resistance would be offered to the downflow of the overflowing vapour, which would be drawn in to make good the loss of elastic force by condensation from the nearest direction. Further, by this means, every overflowing influx of aqueous vapour to this area would be retained as cloud, so that the area of condensation would be upon the above principle somewhat definite in locality in a certain latitudinal position, where we should have such an amount of vapour saturation in the air as could no longer be maintained in the vaporous or cloud system, but must fall as rain.

d. The conditions previously discussed for the continuity of an aerial system from equatorial to polar regions, would be active for purely aerial forces only in dry air, and the vapour forces would fall far short of the polar area, for condensation of the largest amount of vapour in moist air; as such vapour forces would not be able to

lastic gaseous systems for the greater part of the
ney embody, very far from the tropical area where
apidly lose its sustaining force upon them. There-
force of vapour projection would be nearly lost
sive condensation of vapour that would occur, and
duced by the condensation would not only cut off
rce of the overflowing currents, but would retard
wing projections beyond, and induce them largely
vitation forces of the condensed cloud system that
ing locally into rain. Under the above conditions
as proposed, at a certain distance from the equator
sation, which, if all forces were equal upon the sur-
, would surround the tropics as a band on both sides.
evertheless imagine that if there were any specific
sation in any part of such a band, as for instance
f greater declination to the sun's rays, this would be
r proportional terrestrial radiation, and the conden-
centrate particularly near such position. Further,
ea, whether wide or local, the overflowing vapour
s elastic resistance, would be directed by the sur-
l gaseous expansion, and the vapour condensation
stantaneous, aerial forces from polar directions as

tures, but this I am unable to follow. I presume from geographical observations it occurs at about thirty degrees of latitude from the thermal equator for the time; being influenced also by the local radiational force of the area upon which the system is superimposed which makes it one of greater or less latitude.

h. One matter in the above is important, namely, that by the superior weight of vapour condensed to water or cloud over gaseous vapour, the condensation produces a *descending area* or causes descending currents. The condensations offering at the same time space for the presence of such by contraction. Further, the rain system produced by condensation drags a certain volume of air by adhesion downwards with it. We may thus imagine that the whirl system, shown Fig. 176, page 439, would, by the addition of a descending force, on its polar side be completed in an elongated ovoid form, terminating at about 30 degrees of latitude; for we have now by this descending force the four sides of our whirl supported by active tangential action. Further, we have in such a whirl by the continuity of flowing forces a system, which once induced, would support the continuity of the weaker, that is, the descending side of the whirl, that would bring about continuity of whirl projection, even when the descending force was very weak, or possibly even at times slightly negative. In this manner the whirls proposed, 154 art. shown at W, Fig. 176, are rendered so far complete that a large element of the whirl motion would be continuous in areas lateral to the equator extending 30 degrees N. or S., more or less according to local and seasonal conditions over every area where evaporation was sufficiently active to nearly saturate the air.

i. We must, however, in the above conception observe that the fourth side of our whirl moves constantly to denser air as it descends, as before shown, by which although the air and vapour may be assumed to constantly change density from resistance to resistance downward as the flowing force is impressed, nevertheless the resistance encountered by the lower air is a constantly retarding force, and it is therefore only by condensation of the vapour to water that it gains sufficient gravitative impulse to enable it to be pulled through the complete whirl system.

j. Under the above conditions it is most probable that the resistant descending side W, Fig. 176, of the whirl generally forms a conoid of impression and divides against the resistance of the denser air, so that a biwhirl is again formed upon the resistance of the earth's

hirl of which only enters by underflow into the
orial system, the other being deflected outwards
the circumpolar area. This would possibly cause
ertical aerial whirl system to take the form repre-
ollowing diagram for vaporous aerial systems, par-
ceanic areas.

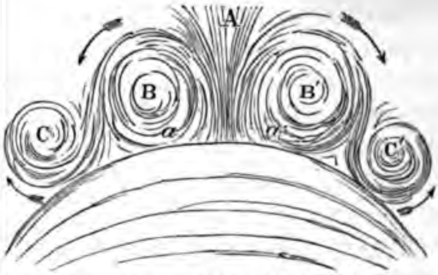

Fig. 177.—Diagram of Vertical Biwhirl Systems.

a cone of resistance formed by continuity of projec-
elastic forces.

hirl engendered by conic resistance at A, the whirls
flection into their own system as shown at *a*, *a*′.

ndary whirls formed by tangential forces thrown off
or of the whirls B, B′ by a cone of resistance upon the

sations will upon the whole engender or pull forward a general flow of air in the same direction; by contraction of bulk in proportion to the extent of the elastic vapour force still retained. This will partly account for the direction of aerial surface currents northward by contraction upon the cold surface of the globe.

l. By the conditions of descending visible cloud currents, we have not the necessity of the descending region being a more rainy one than contiguous parallels of latitude, in fact there are some reasons that it should be less so, unless the downflowing current meet a cool surface. This is seen in that the downward pressure upon the air would increase its elastic force in such a manner that it would be able to maintain proportionally more vapour, so that the vapour would not be condensed until this pressure was somewhat released by lateral deflection and expansion.

m. It is also necessary to limit the extreme projection of a vapour system under condensation, as considered above, to oceanic areas where continuous evaporation is possible to support it. Thus it would be materially interfered with by such extensive tracts of desert as occur in parts of Asia and Africa where the dry land area is for a considerable distance continuous. Indeed in this case we must for the most part omit the consideration of the condensation aqueous system altogether, as the air is so much under saturated that it maintains its vapour as a purely aerial system whose overflow and underflow may extend from polar to equatorial regions upon principles discussed, art. 40.

n. We have evidence in several instances of the purely aerial system being persistent by continuity of overflow. Thus, over the great mass of northern land forming Asia, and by continuity in a north-easterly direction of the larger portion of Africa, which immense district has but the small discontinuity from the presence of inland seas which are not extensive. Here it is said that the north-easterly winds which take the direction of the oceanic *trades* flow continuously during the time that the sun is north of the equator. There is no doubt that this inflow is mainly due to the expansion of air only by the sun's heat being now greatest upon northern areas, but the fact that the same winds do not uniformly traverse equally oceanic areas is due to the presence of vapour, which must be manifestly increased in air traversing an entire area of constant evaporation. The aerial system is therefore one of greater amplitude in proportion as its mass is more dry, so that we have not over land

al whirl complete in about the 30th parallel of lati-
verflow continues as a purely density system until its
reduced by radiation in the polar regions, upon prin-
, 140 art.

eeting-place of oppositely directed aerial fluids
ator is not an area of great atmospheric pres-
contiguous areas are so.

een by previous discussion that although the locality
the equator for inflowing aerial currents is an area
nd therefore of more compressed air at the earth's
soon as the inflowing air is deflected by the resist-
imate verticality, that the direction now taken by
ir would project it upwards; therefore, although the
upon the globe would suffer lateral compression,
ould at the same time tend to remove a part of the
e above the area of deflection by the upward direc-
flowing lateral currents. Thus the locality of opposite
d *not be a parallel of greater aerial pressure upon the*
he direction of deflected forces might possibly *be one*
though of the largest amount of superimposed aerial
is important it may be useful to explain the prin-

points C and C′. Pressures at the equatorial area A being proportionally less. This is evidently the actual condition, and I assume the principal cause of minus atmospheric pressure observable near the equator.

158. Effects of the earth's rotundity upon aerial fluids inflowing towards the equator.

a. In flowing fluids we have heretofore considered the flowing force as following the outline of the earth's surface; it is quite evident by natural laws that material bodies can only flow in this direction by deflection under the force of gravitation, as we are fully assured that it is the property of all bodies impelled with any force to proceed in direct lines. Therefore there is a constant tendency in a horizontal projectile fluid to move tangentially to its last horizontal position on the earth, which will influence it to move in an upward direction. By the same causes currents, in proportion to the mass-velocity of flowing matter they contain, will have a tendency to tangential projection, except as they are withheld to the earth's surface by gravitation.

b. Now, an aerial fluid in flowing towards the equator will, as before shown, be constantly under the influence of the expansive force of the sun's rays, therefore as its projection continues gravitation forces become less *per volume*, and supposing the globe covered with an equally dense aerial fluid at every point, the expanding fluid will flow with less resistance in direct tangential line to its previous position; every possible deflection being equal to a certain amount of resistance. The influence of the above conditions nevertheless form only a small component of directive forces in inflowing currents, from the constancy and equality of gravitation.

159. Effects of radial velocity upon vertical aerial and vapour systems.

a. The latitude velocity carrying displaced aerial matter in currents has been already discussed in 137 art. for the horizontal motion of these currents. In the above considerations of vertical currents I have neglected the influence of the constantly active force derivable from the rotation of the globe, for simplicity of demonstration, the effects of which, added in all cases to the directions of the overflowing and underflowing currents given, should complete the directions of the projection of aerial matter upon the

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scussion of the active principles of latitude-velocities
movement of the aerial system will now need our
for a few particulars only, that the discussion of
rections of vertical currents have now rendered
lation to the surface of the globe over which these
has already been shown that by thermal forces
ve a rising force over tropical areas; there is also
tion, that as aerial fluids rise from this region, the
from the centre of the earth will also increase; thus
d projection from thermal effects, the circumferential
es relatively less, and in this we have an additional
rnly drifts increasing with elevation. It, therefore,
by composition of these force-directions, that there
tendency for aerial fluids to take an *oblique* upward
tropics, *westward from the surface of the globe.*

hese causes, if the earth were an equally frictional
lution, and equatorial whirls were engendered by
d, 116 art., and by condensations, 117 art., such
mpleted, then we should have surrounding the globe
piral whirls, whose motive planes would be oblique,
stward towards the equator, and falling to the east-
the polar area. The equatorial zone by conditions,
l then from upward projection be a band of low

of contact upon this resistance, and overflowing currents that are deflected from it, as they overflow, take so much of the revolution momentum of the equatorial band, or plus velocity to the latitude into which they now overflow, that they, relatively to the earth's latitude-velocity in moving towards polar areas, possess in overflowing, a strong easterly drift.

d. By the whole of the conditions given above, it will be seen that the inflowing currents, as they first rise in space, have a strong minus momentum to the greater circumference and latitude-velocity of the earth, so that they rise with a westerly drift. That this drift is finally and gradually lost by friction on a static equatorial band; whereas thermal impulses being continuous, these, in overflowing outwards from equatorial latitudes after a certain distance from the equator, have their direction reversed relative to the latitude-velocity of their new position so as to take an easterly course.

160. Influence of land resistances upon vertical atmospheric currents under displacement.

a. As the conditions of land resistance vary according to locality, I will discuss this matter for one area only; and that upon general principles, omitting many details that evidently represent active forces in the system.

b. By the disposition of land and water I have pointed out the probability of there being established, two great horizontal whirl systems in the northern hemisphere; the movements of which are particularly shown, 140 art. In this case the direction of mountainous land on the north-eastern coast of South America was shown to materially influence the deflection of equatorial horizontal currents in the North Atlantic area. Now, we can imagine that the same influence would also deflect the westerly vertically directed currents, as previously discussed; that is to say, that a given resistance, as a mountain, situated in a direct flowing current, would not only deflect the current round its sides, but by its inclination, upwards as well. Therefore, such mountainous land opposed to the westerly directed rising currents would give these currents greater inclination to rise, so that, especially near the eastern coasts of continents that resist the equatorial currents proceeding from oceanic areas, the whirl plane would be thrown upwards obliquely by such land resistance.

re some further conditions which establish the locality
ıe plane, as, for instance, in the North Atlantic, by
have pointed out in 144 art. of the natural frictional
hat must occur at the meeting of two whirl systems
ion of land resistance. In this case, at about the region
ean Sea, I have shown that there will be a reflex whirl
ific system which will fill, as it were, the interspace
Pacific and Atlantic whirl systems. This reflex whirl
ed *a* in the diagram, Fig. 168. If such a complement-
ist it forms a further resistance to the direct projection
ly drift of the rising and overflowing equatorial current;
cause greater deflection and produce further elevation
causes previously discussed of land resistance only.
is possible that the whole plane of the N. Atlantic whirl
ıese causes, is thrown oblique, having its highest point
ver the Gulf of Mexico, and its lowest about the Azores;
ıomentum of the downward aerial drift may be per-
ıs barometrical pressure, as before stated.

ove assumption of an oblique whirl-plane, does not
at there will not be also surface whirls, as previously

certain strata of the air only to take a smaller and differently directed area of projection.

e. The purely aerial forces are completed in the plane of gravitation equilibrium suffering possibly deflection to whirl-current lines above the areas of vapour condensation, maintaining at the same time, by bifurcation, their direct projections over dry land areas in the direct whirl lines proposed, 140 art., aerial forces being deflected to the earth at a much greater distance from the equator than the vaporous.

f. The principles of this oblique plane of aerial motion under the influence of vapour forces, for the North Atlantic area, may be represented roughly by the diagram Fig. 179 where the dotted line represents the equatorial surface. The directions of forces shown about the arrow under A are represented impinging upon the area of resistance of American coast towards B, shown by shading to the right, here meeting also the reflex whirl above B.

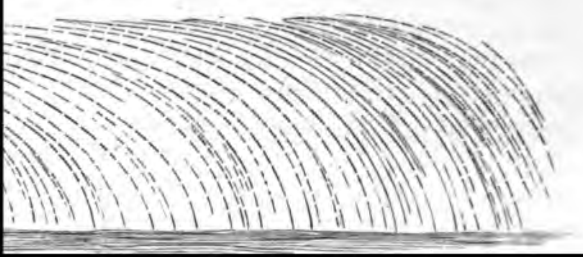
g. The oblique overflow is directed downwards, the whirl impinging upon the surface of the globe in about lat. 20° N., long. 45° W. The superaerial system (Fig. 168) not being here shown.

161. Terrestrial surface resistance to winds.

a. By the general adhesion of air to all other bodies, its movements over the earth cause a deflection of flowing forces downwards to the surface in whirls, as previously discussed for other cases of side resistance. The whirls thus formed are general over every kind of terrestrial surface, being of small amplitude over still water; of greater amplitude over rough water and level land, and still greater over irregular hilly land and in front of obstructions upon it, as of mountains, trees, or rocks. This frictional deflection would, therefore, produce whirls of rolling contact from overflowing currents, the dimensions of which would vary from fractions of an inch to several hundred or thousand feet, according to the velocity of the current, and obstructions capable of engendering conic resistance, the general conditions of which will be the same as those discussed, 98 prop., for cohesive and adhesive systems of fluid matter, or for near surface, by the conditions of rolling contact demonstrated, 46 prop. *b,* and otherwise.

b. The immediate influence of resistance to aerial currents at the earth's surface may possibly be best observed by the directive impulse that the air gives to the drops of falling water in

drops themselves being drawn down directly by
motive impulse of the wind enters into composition
tion. In this manner, supposing the air in currents
form velocity at a certain height and at the earth's
s the air increases in density, and consequently in
qual velocity, the falling drop near the earth's surface
erated by gravitation about in equal proportion to
density or momentum of the air, so that its fall
que in a nearly direct line. But if the earth's
uctions thereon offer resistance to the current so as
the paths of the drops become by this cause para-
ir nevertheless by its momentum could not deflect
o its own curvature, but only as the impulse of its
n the surface of the drop.



side most direct to the wind. The rain and wind drifted also up the dome, moving evidently by rolling contact; this could be clearly made out by observation.

e. It is possibly to this cause we owe the greater amount of rainfall, that has been observed to take place, at a position a certain height from the ground than at a few feet higher. This Sir John Herschel mentions in his "Meteorology"[1]—that Dr. Heberden found in twelve months from July 7, 1766 to July 7, 1767 the amount of rainfall at the top of Westminster Abbey to be only 12·099 inches, while at the top of a house close by, much inferior in altitude, it was 18·139, and on the ground 22·608 inches. Thus also Mr. Phillips found the fall of rain at York for twelve months in the year 1833–4, at the height of 213 feet from the ground, to be 14·963 inches, at 44 feet 19·853 inches, and on the ground 25·706. Similar phenomena being observed at Paris and elsewhere. There is no information as to position of lower catchwaters whether exposed to north or south. Sir John Herschel says, "The effect cannot be due to *obliquity* of fall at higher than at lower level since the same quantity of rain must fall on the same horizontal surface after changing its obliquity as before." I am unable to see the force of this argument generally, but understand it to be perfectly true for an infinite area of rainfall; but rain falls for the most part locally in very irregular quantities and varying intensity, and by the general principles I have demonstrated, will be deposited most where there is space for incurvature of its path to deflect it downwards. This may be very clearly observable frequently with snow, which we may take for argument sake to be visible rain, although of less density in proportion to surface exposed. Snow may be observed in windy weather upon hilly lands drifting along so nearly horizontally that the land surface is left quite bare, whereas in shady places, or where there is greater space to direct whirls downwards, it deposits continuously. I anticipate also, that the greater deposit in the extreme cases given by Herschel, there would in all instances be found some obstruction to the direct action of the wind to cause local whirls. Further, the same observation of the horizontal direction of snow just given may be witnessed in the case of rain if we are placed in a lofty exposed situation, as may be seen by the horizontal position that we are compelled to carry the handle of an umbrella to protect ourselves.

f. With a perfectly direct rain, falling by gravitation without wind, ere will be little difference in the amount that falls l surface, unless there is much greater difference of the instances given by Herschel. On mountainous s, which possess northern radiational fronts by the t of downward deflected whirls, an overflowing nt will deposit its moisture much more readily here plain, as the extent of resistance would destroy the of direct horizontal projection, and the cool surface antly condense overflowing vapour.

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[1] 8th Edition, *Encyclopædia Britannica*, article "Meteorology," § 109.

frequent evidence of vertical surface whirls in hot r, when this is accompanied by winds which blow at ace from some northerly point. In such cases, clouds , move from a southerly point, the aerial whirls, of rm a part, being deflected to the earth in a more de. The northerly wind we experience is the reflex irl or counter current. In such cases of very hot , storms commonly follow to the northward.

onditions also occur in mountainous countries from ds, which by whirl deflections overflow in such a cold *southerly* wind is experienced upon the earth's positions for a certain time. When the wind is stant and regular whirls of smaller amplitude are pro-taking possibly, if the land is unclouded, an approximately equal time for equal space projection in the upward side of the whirl that it takes in the downward side over the oceanic area.

b. I anticipate that there is a general local whirl system over every land surface exposed to the sun's direct rays, and that the projectile force is greatest over portions of land which present the least declination to the sun. The deposition of dew, so satisfactorily accounted for by Dr. Wells, I think might possibly, in certain cases, as regards its amount, be due to the reflex action of vertical whirls bringing air of minus temperature charged with vapour by return whirl currents, at sunset; particularly from the sea. We may further observe that as it is the property of water by convection currents, active under differences of temperature through surface radiation, to bring about a constant change of its parts, so that the warmer or lighter parts are constantly brought near the surface; it thus follows that water by radiation will be constantly giving out heat to colder air, should this exist above. Therefore in winter the positions over the sea and near the coasts are warmer than inland. By the same conditions, as just discussed for rising currents over land, it follows that at certain times air resting upon warmer open water will, by the heat it acquires from the water, form rising currents, which engender by their tangential action whirl projection upon the more static air overland, and thereby produce overland winds and rain or snow; unless such whirls are otherwise deflected by forces present, as by the influence of prevailing winds along the coast.

163. Cyclones.

a. I assume all atmospheric motions to be *cyclonic* by principles of rolling contact and conic resistance, fully discussed. Cyclones being engendered by every plus or minus pressure in parts of the atmosphere from any cause. The most general source of the larger cyclonic motions of the atmosphere is most probably derived from local condensation of vapour into cloud or rain. As we find vapour condensations from contact of cool currents or from surcharged electricity of one sign are *sudden* from the point of saturated air to cloud; in like manner, from the same cause, cyclonic propulsions are generally *impulsive*, and resemble exactly in principle whirl projections of the class described, 67 prop. *e.*

b. In tropical latitudes, the vapour and atmospheric projections

y in an upward direction to the westward, as before
by a sudden condensation of vapour to cloud, a
projection of the more easterly vapour area towards
ly condensing one, and the concussion of meeting
rical discharges with immediate downfall of rain.

cal or temperate latitudes the normal conditions of
pour forces will be to direct currents downward to
he globe (154 art.); these projections being thrown
of resistance take *biwhirl forms.* In this case the
of the biwhirl is carried towards areas of *greater*
city; and from its inclined direction being *east-*
atorial side of the biwhirl may be *suppressed,* from
f easterly momentum over the normal. On the other
ior, or polar side of the biwhirl now represented by
being deflected by whirl projection to latitudes of less
on velocity, thereby *gains easterly momentum* so that
rce is increased. From this cause generally winds in
rotate from right to left in the northern hemisphere,
o right in the southern.

c action there is a general tendency of the cyclone to
the polar area by its deflected currents impinging
and suffering thereby greater condensation upon the

whirl systems would be formed, which would remain fixed and constant, the vapour these whirls carry being uniformly condensed at a definite area of deflection, where indraught contact would be established with cooler circulating currents.

164. Hurricanes.

a. Hurricanes occur where there is the greatest extent of equatorial oceanic projection and the greatest amount of resistance from western oceanic boundary. These conditions are met in the North Atlantic, Indian, and North Pacific Oceans. Similar conditions are also met with in the Southern Pacific as regards oceanic projection, but the resistance of land being imperfect to the south of the Eastern Archipelago, from New Guinea to Australia; from the influence of Torres Strait, the southern equatorial projection thus loses a part of its impulse and adds this part to the Indian oceanic system, so that we have here no considerable hurricanes. In the Southern Atlantic the equatorial currents are deflected by open oceanic areas towards the northern system (126 art.), and thereby lose a part of the southern whirl deflection, such as would naturally be produced by a normal resistance to the impulse of the westerly equatorial current. Therefore a part only of the southern equatorial aerial projection is thrown overland in moderate cyclonic action to greater distance into the valley of the Amazon, so that this can scarcely be pointed to as a region of hurricanes.

b. For more exact conditions it will be convenient to take one area of hurricane projection in consideration. The area of which we possibly know most is over the North Atlantic, where we have the record of so many hurricanes that we may fairly depict within wide limits the average hurricane path.

c. If we accept the general principles I propose of one great ellipsoidal whirl system being active partly over the North Atlantic area, so that the ellipsoidal aerial circulation has a focus approximately in about lat. 33° N. and long. 50° W., and that a *complementary* cool whirl meets this, thrown off the Pacific system about the Caribbean Sea; the meeting-place becomes at the time of condensation of the western equatorial projection upon the cool whirl, one of minus pressure. This condensation by contraction of mass increases the impulse of the westerly equatorial aerial drift, and as by general cohesion the whirl system continues its impulses of induced velocity under deflection into the ellipsoidal path, it carries

ıward into the Atlantic Ocean; throwing off certain
force tangentially at the region of greatest curvature,
e interior of North America.

w consider the conditions of overflowing forces only
rth Atlantic area in about 30° to 40° N. lat. we have
theory, the greatest activity of overflowing vapour
re active in completing the overflowing equatorial
). Therefore along this parallel, assuming sudden
f vapour into cloud or rain to occur, we have at the
condensations a local minus pressure, the effect of
again, as by causes proposed in the last paragraph,
which the impulses of the ellipsoidal whirl will be
ated in that part of its path which is towards the
ion of the ellipsoidal system, or about the position of
n Islands. If the condensations over the Caribbean
e equatorial whirl with greater force at certain times
nd the condensations of the overflowing whirl are
me periods, we have then, by the conditions by dif-
l pressures, forces capable of producing a *hurricane.*
causes as the above the general ellipsoidal currents
less accelerated around their focal points, and as we
every flowing atmospheric current to make rolling
ontiguous quiescent or differently directed parts; the

which, having force to deflect the whirls constantly backward upon the projection, will in this case resemble the projection of a solid, as of a ship in water.

d. The cone of impression or anticyclonic area will occur generally over land where the earth's friction offers the greatest resistance to the direct force of the flowing current. Where currents are constant the anticyclonic area might be frequently clearly mapped for position upon the earth just in the same manner as whirl systems can be mapped for oceanic currents; always remembering that a cone of impression in a fluid is formed at a distance in front of the resistance. In cases where air and water are flowing in one uniform course upon the oceanic surface, as before pointed out, there would be less resistance than in the case of the air moving upon static land surface; further, the resistance would be greater, as before stated, in high lands and mountainous countries, which by their elevation would support the cones of impression to wind impulses more rigidly than upon level plains or water surfaces. We also find that regions of large radiational surface, where the air is cold and therefore condensed, form resistant areas to lighter airs, which have their densities further increased by the impingement of flowing force upon them, although the flowing force would be mainly deflected by whirl motions into areas of less resistance.

e. By the above conditions certain regions of the earth constantly receive the impulses of aerial projection, particularly where such are derived from the carrying force or minus friction of oceanic currents. These are regions of high barometric pressure under normal conditions or permanent anticyclonic areas (cones of impression).

f. In the anticyclonic area, as it is termed, the cone of impression engendered by any form of resistance is a condensation of the air in the condition that it happens to be at the time, such condensations by increasing the elastic force render any vapours present invisible, and produce fine weather over the district affected. It will be seen that the above propositions reverse the generally accepted doctrine—that the cyclonic area is one of ascent, and the anticyclonic one of descent. Upon the principle of whirl motions they would be the opposite of this, and I assume this to be the case so far as horizontal motions of a cyclonic character are concerned. It is nevertheless quite clear that a descending current would produce a pressure if it impinge on an area of resistance, as any part of the earth's surface, or if it act in such a manner that by its direct impulse it forms a

ce. Such special conditions I have discussed already
tions (154 art.).

c motion in the air productive of rain.

erally assumed that there are rising currents in the
ones; but if we may take evidence from the whirl
ble gravitating matter, as of liquids in whirlpools, it
the reverse of this; the tangential exterior forces of
ing current, by rotation alone, removes the lower cen-
tangential action, and causes thereby minus pressure
tre. It appears to me probable, however, that there
es a vertical downward inflow of the more rarefied air
ich partly equalizes that removed by tangential force
rial surface.
the cyclonic centre, as here proposed, to be one of
from the tangential velocities induced, by a con-
producing exterior plus pressure in whirl motions;
of such tangential force, if it act as proposed, that is,
visible in aqueous systems in whirlpools, it will ex-
om such centres by tangential action. Now the result
aerial or vaporous mass of equal elasticity, would
the central elasticity; therefore, for any aqueous

by the latent heat of condensation of vapour which will again make such condensation much more rapid, and under certain conditions, by direction of vapour to the area of condensation, might make the rainfall enormous near the axis of revolution. This would be a probable cause of a rapid downflow in a small visible cyclonic area, but whether answering to a water-spout I do not know, although it appears to coincide with certain descriptions that I have read, but have never actually seen. There is also a further condition in small intense cyclones, which answers to the general descriptions of water-spouts, that is, that the centre of the cyclonic area is by the action of tangential forces an area of less atmospheric pressure, and the cyclonic circumferential area one of plus pressure. There would therefore be over any surface of water on which such a cyclone rests, an inscribed circular area where the water would be elevated in the centre by the minus pressure, and this may even, near the axis of greatest intensity, elevate the central waters into a conical form until it meets the axis of the cloud system above, which by the tangential forces acting on the surface waters, causes it to form a part of the system. This would be exactly the reverse, but upon the same principles of tangential rotary force as we find active in the formation of a *whirlpool* which produces a perfect pointing of the superficial air downwards in the rotating water where the whirl forces are active. It is most probable in the phenomena of water-spouts that the whirl has a downward direction through condensation as well as a horizontal whirling motion which causes a circumferential pressure over the area on which it rests greater than the difference of atmospheric weight as it would be caused by a purely horizontal motion. It is possible certain forms of water-spout are produced by electrical conditions which I cannot now discuss. Dust whirls appear to be produced by the same conditions as just discussed for the elevation of water in water-spouts.

168. Causes of local changes of season—climate.

a. Continuous observation for years has proved that we may fairly plot upon a globe mean local annual summer and winter temperatures and pressures, which will remain approximately constant in certain positions. The same will apply to rainfall areas, so that local changes of season which appear to us to take considerable ranges of differences, are really active within very definite limits of change for most districts. It is very clear that the uniformity of such local

ve observe, depends upon the nearly equal intensity
eat under an equal obliquity of the earth's axis, the
olution velocity of the globe, and the permanency of
areas of land, water, and ice; so that we can imagine,
and conditions were quite constant, we should have
ng circumstances at the same annual periods. There
ore, such changes from average annual conditions as to
rtial differences we observe, and these changes most
definite laws, which we may utilize for prognostica-
re so successful as to discover them.

ervations of many philosophers there appear to be
he sun's annual heating influences ranging in periods
years, depending, as is reasonably inferred, possibly
nt of spots upon the sun's disc. A periodic difference
heat from the sun may be otherwise possibly due in
ggested by Sir John Herschel,[1] to the influence of the
upiter, whose revolution is in 11·9 years. In our
e causes of gravitation it may probably occur that
ce between the sun and planet excites the heating
e sun, or the reverse of this. For our present pur-
be the differences assumed, in the annual heating
n's rays, there will be differences of vapour impulsion

be fourteen millions of miles; the least, half a million. The influence of such changes of ellipticity is found in that the sun's rays penetrate the atmosphere with greater force at one period of the year than at another. Perhaps the most important effect produced by variation of ellipticity is seen in that as we approach nearer the sun in winter, that this nearness aids in maintaining northern oceanic areas open to the drift of currents at this season. These differences must also be important, as pointed out by Mr. Croll, in their influence upon the amount and extent of snow that may be deposited or may remain in polar regions. This deposition being even possibly so great at certain periods as to lower the oceanic surface, and affect by difference of gravity in polar regions the general distribution of fluids upon the surface of the globe.

e. By the precession of the equinoxes and a general change in the direction of the major axis of the earth's orbit, our present relative winter position of being nearer the sun than the southern hemisphere will in about 10,400 years be changed to the opposite condition, and the southern hemisphere will take our equivalent position. Under this change, by the same causes as discussed above, § *c*, the northern will become the colder hemisphere in winter, and the directions of currents will be naturally changed by the advance of arctic ice.

f. The *obliquity of the ecliptic* which produces our seasons is at present about 23° 27′. This obliquity diminishes on an average not quite half a second a year. Such change in a short period would evidently produce only small results, but as the force of projection of thermal atmospheric currents into polar areas so materially depends upon the amount of obliquity, such small changes cannot be without influence.

g. Supplementary to the above conditions, we have *nutations*, which render annual conditions irregular. The whole of the above changes tending at the present time to make the northern hemisphere colder in winter; although these differences may be conceived to vary the amount of thermal force in either hemisphere slightly only in short periods. Nevertheless, with regard to minor local climatic changes, the course of projection of an equatorial current may be materially influenced by very small differences in original direction and by the positions of the local resistances which it afterwards encounters by which it may be deflected. The directions and deflections of equatorial currents will again rule the position of friction-whirls necessarily formed contiguous to them, by which

ons are much influenced. Changes of direction being
ly active in the local complication of whirl systems
ral equilibrium is most sensitive; as, for instance, in
of the United States of America and of China
These changes again extend their disturbing in-
to the current systems normally established as in
to the British Isles.

**hed aerial currents produced by astronomical
constant tendency to modify the configuration
of the globe to the conditions present.**

al causes for conformation of motive oceanic forces
conditions were pointed out, in 125 to 131 articles;
ditions being also assumed to most materially in-
al. There must also necessarily be a certain influ-
position of terrestrial matter due to the action of

tion of the sun's direct rays, and by frost and rain,
ocks of the earth become disentegrated, and by the
winds the disintegrated parts in dry weather are
Therefore, where the wind is constant in one direc-
particles are drifted by successive movements to

SECTION III.

AQUEOUS SURFACE WAVES.

CHAPTER XV.

FORCES ACTIVE UPON LIQUID SURFACES WHICH ENGENDER WAVES. PROTUBERANT, COMPRESSILE OR LOOPED SYSTEMS. CONCHOIDAL FORMS. VELOCITY OF PROPAGATION. TANGENTIAL ACTION. MOTION FROM ROLLING CONTACT OF MOVING AIR. WHIRL IMPRESSIONS. DIVISION IN SEPARATE UNITS BY OVERFLOW. DIVISION BY CORRUGATION.

170. Conditions under which waves are formed.

a. A liquid surface, by the perfect mobility of its parts moving sensitively to the constant equal action of gravitation upon it, is, when at rest, in a state of perfect equilibrium. In this state any part of the liquid surface may be represented as a body resting upon a perfectly level plane of repose upon which it is free to move, when impressed by any directive force whatever, capable of overcoming its mass inertia, and the resistance of cohesion to other parts of the liquid system.

b. Now, as we find a liquid surface in the state of equilibrium of repose, is of less superficial area than the same surface would be if under any possible state of disturbance, we may conclude that *any exterior action that disturbs this surface will produce greater surface curvature upon the whole or in parts, and that this curvature will necessarily form either protuberances or hollows, or a combination of both.* Such protuberances and hollows as may be formed, meet conveniently the general denomination of *waves.* Therefore a wave *is caused by any possible motion that disturbs a liquid surface* from a state of rest. Taken in this manner, we may conclude that a wave is the *resultant* of one form of motion or another which produces surface disturbance. In open water, as in the ocean, it is

ltant of all component forces that may be active
surface. Waves will therefore have as many *modes*
s there are means of disturbing the liquid surface.
nes important in the investigation of the subject
is by no means necessary that free fluid matter
ted by one system or direction of forces only to
out rather that waves are the necessary consequences
disturbing influence. Neither is it necessary that
be of one form or dimensions. One constant con-
is evident, namely, that gravitation enters into com-
s uniformly through all other disturbing influences,
s to induce a uniform system of motion, which may
itation plane as little as possible.

lity of propagation of forces in fluids to a distance,
n the motion of a solitary wave referred to, 34 prop.
otion of sound through air and water. A general
ation of forces to a distance in fluids, is probably by
molecule to molecule. The principle of which is
xperimentally in the propagation of an impulse
straight series of hard balls of equal size suspended
each other and resting in equilibrium. In which
e strike one of the balls at the end of the series by

e. A free liquid being a perfectly mobile system of matter, and the air resting above it being also in a free state and of great elastic flexibility, possessing also a certain function of adhesion to the liquid, it is presumable that any force impressed by adhesive moving air above sufficient to overcome the resistance of the system of the liquid at its surface, would move a portion of this liquid forward upon or within that in front, and as the liquid is assumed incompressible, this motion would necessarily produce a protuberance upwards into the air. The air always offering a plane of less resistance than in any other possible direction for the displacement of the liquid.

f. Now, taking the ordinary conditions that surround us, we observe that a surface of water may exist as a level plane when it is undisturbed; or it may have protuberances or waves engendered upon it, as, for instance, the ocean may be calm or rough. It is also quite clear to us that certain exterior forces, as the wind when active upon the surface of the water *do produce the roughness*, or the motions we term waves. We also conclude that waves are not produced upon the ocean unless such exterior forces are active, excepting ripples derived from currents. It therefore becomes reasonable upon the above premises, which is all important for our investigations, to assume:—*That any force whatever that is capable of producing the wave will be certainly capable of maintaining its existence*, so that the principles of the genesis of the wave is the demonstration of the conditions of its continuity; both phenomena being clearly derived from the same set of motive causes. Further, we may assume that if the wave-producing force, whether wind or other agency, should cease to act, that there would be still constantly present the active force of gravitation, which would cause the surface to return to equilibrium in such space of time that the potential of the elevated wave could dissipate its force, by composition of its initial momentum derived from the disturbing force, with that of gravitation, and of resistance by molecular friction, ever present.

g. In the above conception of the subject we meet with two important conditions that may be conveniently and separately considered:—Firstly, the elevation and maintenance of waves by the impression of exterior forces; and secondly, the dissipation of waves, or restoration to equilibrium by the evident action of gravitation; and as we may assume that all wave motions are caused by exterior forces, active in the first instance upon a surface plane

ay further observe that the elevation of the wave
hatever, applied upon or within the surface of the
narily possess a mode of action *contra* to the force
The active conditions being generally, that if the
remain the same, a portion of the water *below* the
tion equilibrium in one position is elevated *above*
ther. If the entire surface of a liquid were equally
force, this surface would equally resist in all its
ves would be produced. It is therefore necessary,
f wave motion, that there should be *local impression*

atural force-system that we may consider is that of
upon water. The wind, by the irregularities of land
ace, as also by the necessities of its rolling contact
these irregularities, becomes itself very intermittent
n of its direct momentum upon any object upon
es. This we not only feel in the intermittent gusts
ur bodies, but we may observe it in every mobile
nfluence, whether it be wind passing over a field of
ng of a leaf, or the oscillation of a blade of grass.
blows powerfully our ears are also sensitive to the
nd we know that this is caused by the intermittent

surface will throw more or less liquid on certain local positions, and we can again imagine that this excess or deficiency, separately considered, will find no position of equilibrium until it is dissipated or diffused throughout the surface of the entire liquid system of which it forms a part. Therefore we may conclude that any increase or decrease of mass elevated or depressed locally would be as a free body of liquid urged constantly by gravitation over the surface until it finally found rest by distribution to equilibrium.

j. Under the above conditions we may imagine that any force of displacement in water, as for instance, that caused by the launch of a ship, would by the local elevation, that the pressure of the intrusion of the hull of the ship occasions, throw the whole aqueous system of the ocean out of equilibrium. Theoretically, this would be so, if the system of the ocean were in perfect equilibrium to gravitation so as not to be affected by intermittent or other opposing forces. But at the same time we must conclude that the pressure by increase of bulk of liquid that the ship would throw above gravitation equilibrium, would only represent a certain force that would be active upon the inertia of the mass under equilibrium of gravitation already established, that is, active upon *another force.* Therefore the pressure caused by increase of bulk of the ship would combine with the force of inertia of the system under equilibrium of gravitation by general laws of resolution of forces, that would cause a certain displacement of a *part of the liquid system,* which would afterwards move to equilibrium in equation with the motive values and directive influences of all forces present.

k. We find when we further analyse the above, that the mass of water elevated by a force, as for instance by the intrusion of the hull of a ship, would have by its horizontal projection lineal with the surface of the water a certain momentum, which to diffuse itself must move the projected water against the inertia of that resting quiescently near the surface of the area affected; therefore by the equality of inertia volume for volume of the projected and resistant water the projectile impulse would soon come practically to equilibrium with the resistance; but as we should still have by *intrusion of the ship,* a large portion of the elevated water representing a pressure by its potential force, left above the surface of equilibrium upon which gravity would remain active as at first, the further movement of the elevated water, caused by the displacement, must be practically by the force of *gravitation alone* upon it. The original

entum of the displaced water having been nearly
e resistance of the inertia of equal matter within a
aving only a small residuary fraction of projectile

above conditions we may also imagine that if upon
face there was a depression from any cause, as by
of the ship, assumed previously to be launched,
n would instantly produce a hollow, that gravitation
tely act to restore the equilibrium of pressure by the
parts of the system moving towards the hollow.
, from the action of the surrounding pressures from
here would be complicated directive influences, the
ium being much disturbed locally and the pheno-
plicated, as I will hereafter show.

portant original researches of Mr. J. Scott Russell,
ssociation Reports, 1844, the reading of which in-
ke the illustration above of the launch of a ship, he
entally, the effects caused by increase or decrease
liquid in equilibrium, by two methods. One of
crease of bulk by the intrusion of a body of water
another by the abstraction of a like mass. In these
r. Russell shows that under certain conditions a

like manner be surrounded by hydrostatic pressures, so that the pressures will constantly urge the liquid to fall into the hollow by *Infractions* with a certain motive velocity that will not come to rest until the composition due to the constant forces of gravitation, general momentum, and molecular friction causes it to do so. This principle of motion was first pointed out by Mr. Flaubergues in a paper in the *Journal des Sçavans*, 1789, to which I will refer hereafter for the discussion of the principles of central disturbances.

n. It will be convenient now to follow the conditions of the production and maintenance of waves by protuberances only, and to discuss the mechanical principles by which forces of *compression* propagate themselves upon a liquid in equilibrium; some experimental demonstrations of which may be found in the important papers of Mr. J. Scott Russell. I will leave the conditions of abstraction of volume and of minus compressions in gravitation systems, active upon the surface of water, for consideration in the next chapter.

Deep waves formed by horizontal compression. Looped systems.

171. PROPOSITION: *That the effects of a compression upon the open surface of a liquid will be to move the compressed parts consecutively within the surface plane towards points of equilibrium with a velocity of motion proportional to the mobility of the liquid, and its freedom from the influence of the resistance of solid surface near or beneath it.*

a. The principles of the action of consecutive compressions in a liquid having a free surface may be possibly best considered by taking some of the conditions which may be made visible under certain conditions in solids. Thus, if we take for an instance, the application of a pressure to an elastic body, such as india-rubber, we may assume in this case that the body yields at first at the point of compression, but this point being thrown thereby out of equilibrium with all other parts, that it will in proportion to its elastic flexibility, have the forces of compression that it at first received distributed in all directions in its mass, and if the india-rubber be not fixed and the impressed force sufficient, the elasticity by reaction will move the whole mass forward from the area of compression to a more free area, and thus regain static equilibrium throughout its parts. So that we find the forces impressed in a material elastic

ffer restraint under compression, will react by move-
areas of less restraint, seeking equilibrium as quickly
nd resistance of the parts of the system permit.
in which a compression is communicated to areas of
may be taken in another case for a physically incom-
that is one practically incompressible in relation to
To illustrate this we may place a long straight metal
small diameter upon the level ground and apply a
one end of it. We then find we cannot push it
y a longitudinal compression at the one end, as the
e surface of the ground will offer too great friction
, and that the general inertia of the heavy material
l cause it to bend into a loop rather than continue
force in a direct line; that is, the impressed force
ready to wholly escape to any point of less resist-
ceive it.

ve experiment would be somewhat difficult to follow
exact conditions that I wish to define, we may
atter by placing the metal rod or wire, before men-
in a groove in a piece of wood open at the top as
in the section below.

groove is thrown out of central equilibrium, and that the force of compression moves from the resistance to points of less restraint, which are in this case situated at the open side of the groove. In this direction, therefore, it exerts its force to equilibrate the compression that it receives moving by its flexibility into free space, in every possible direction open to receive it. It therefore *accepts*, if I may so express myself, the resistance of the groove consecutively from point to point. If we were to suspend a free body at the opposite end of the wire to that upon which a compression so resisted was made, it would not in this case move the body during the compression; thereby showing that the distant end receives no part of the force impressed. A mechanical means well adapted to demonstrate a compression, is by the apparatus technically known as a *snail*, shown at A, this being turned in the direction of the arrow, causes a compression continually on the end of the wire.

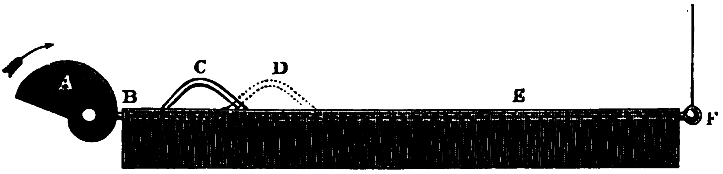


Fig. 182.—Ex.—Loop formed by Pressure at the end of a Wire in a Groove.

e. By the known properties of fluids we can imagine the resistance to compression as being at no point perfect unless the fluid is entirely surrounded by rigid matter. This is demonstrable from the equal mobility in all parts of the mass. Therefore the swelling of the wire about C, which remains in static equilibrium after we have given a certain space-compression at the end, could not remain in such a condition if the wire were a *soft* body or a liquid, as in this case, from the imperfect rigidity of such body, gravity would pull it down and flatten the loop out immediately after the compression had raised it. This would occur, for instance, if the soft body were of the flexibility we recognize in textile bodies, as in a rope or cord.

f. If we take the case of a soft body, as, for instance, a rope pressed as the wire was proposed to be in the last illustration, and assume the pressure at B to be a point of firm resistance; then, on the supposition that all parts of the rope are equally mobile, the pressure upon the loop C would be in all parts in equilibrium;

ion would now act upon all parts equally, the resist-
greater at the point of rigid pressure B. Then the
stem that would be *weakest*, and therefore *the first to*
d be that at the opposite point of contact to B, where
meets the plane of repose. Therefore at this point
he compression would appear to be active and thus
system onwards, retaining its equilibrium afterwards
ce shown by the dotted lines at D. The resistance
strongest towards B, it would move further onwards
a velocity proportional to its mobility and freedom
, until the loop would arrive at the free end F, where
e the impression visible if desirable upon the sus-
that point. In the above we may notice that the raised
in equilibrium throughout its system, and at both
act upon its plane, and that the compression which
progressive is simply derived from unequal local re-
cause the loop to move from the most resistant part
to the least resistant; therefore we may conclude that
ctive impulse given to the loop from the point B will
cause the loop or wave in equilibrium to move con-
l by continuity of impulse, and this would also have
vith the wire except that the immobility of its parts

this loop being in a soft body, the compression or wave formed will go continuously forward, and each part of the rope will rise in succession at a greater distance.

h. This motion of compression free in one direction may also be exemplified directly in liquids where greater mobility renders the motive system more perfect. Thus, if instead of the rope fixed in a groove we have a long trough, a part near one end of which is illustrated, Fig. 183, this being 20 or 30 feet long, by 10 inches wide and deep. The trough being placed quite level, half filled with water; having one end arranged by means of a movable board so that it can be pressed upon the column of water in the trough for a given distance as shown above, from A to B. Then by moving the loose board by the plunger C, this distance, the first effect of the pressure upon the water will be that the water will resist by the inertia of the mass in front and by the adhesion to three surfaces of the trough; it will therefore swell up, as the wire in the groove of the previous experiment, near the point of compression, and thus a loop or wave will be formed, which as a compression will afterwards go forward constantly towards the free end of the trough moving from the point of greater resistance, or compression, consecutively to each freer point in its immediate vicinity, with velocity of transference of impulse proportional to the fluidity of the water and inversely as the resistances of the surfaces of the trough in contact. The force of gravitation being equal upon all parts of the system, the wave retains only a small element of the directive force, this being active to constantly overthrow the equilibrium of the elevated mass in the direction of its original projection.

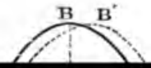
i. To save misapprehension, it should be understood that the impressed force of compression discussed above, must be applied to soft or fluid bodies only as *compression* in the manner indicated, or the equivalent of this; as it is also quite possible to send an impulse or wave along a pliant body, that shall not be a wave of *compression*, as here defined. This may be done by throwing a wave forward with great projectile force in a long pliant body of relatively small gravitating mass, wherein the *projectile impulse* alone may produce a wave in the pliant body, the wave being formed by the release of the consecutive parts. In this case the impulse or wave is *tensile*, to the parts of the pliant material where it consecutively acts, and such a wave may be produced in a chain with loose links laid horizontally along the ground. A wave may also be produced as a

on of parts of a vertical or suspended system. These
ave-motions are merely mentioned to save misap-
ey are forms of motion that have possibly no equiva-
l waves, or at least so, in the cases that I am now

ilibrium of a Protuberant Wave.

SITION: *That a protuberance or wave formed by com-*
iquid will have an initial energy of propagation if its
ure is out of central equilibrium; the motive direction
wave, being towards the side of the figure where the
as the greatest protuberance and is supported upon the

d waves formed by compression, the influence of the
nay be entirely neglected after the wave is once
gravitation figure may then insure the continuity of
n upon a free surface. This is shown in the diagram
nay be taken to represent either the outline of a loop
pe, or the contour of a surface wave upon water.



liquid; whereas gravitation will be more active at C′ than at A, and the *curvature of support* B′ to C′ being greater will be less rigid. Therefore for the stability of the loop or wave, the liquid at C will move forward by excess of compression through gravitation above it and greater curvature in front, and A will remain more rigid by less curvature, and fall by gravitation upon its own surface. As water is practically an incompressible fluid and therefore gravitation acts equally in all parts of it, the wave must go forward constantly to maintain the loop system, so constructed out of static equilibrium, and if such a form of mobile gravitating mass could be rendered frictionless upon its plane of motion, it would be possible, by the principle of continuity of momentum, as there is no part of the system antagonistic to the direction of the wave, that it would go forward eternally. But the molecular friction of any possible moving fluid matter will cause the wave or loop to gradually subside by constant loss of impulse upon the surfaces of resistance, present in any possible containing vessel, or medium.

c. The wave of the form here given being out of central equilibrium for its entire figure upon the water surface, will produce a slight depression upon the front of the wave, below the average surface; but as this hollow will be only a weight deflection of the rigid system of resistance of the liquid mass, it will not be great, or affect materially the general principle of equilibrium of projection, here proposed.

173. PROPOSITION: *The compression that forms a loop or wave within a horizontal mobile system in equilibrium acts as a motion of displacement of the compression in the mobile system of energy, in comparison with other loops or waves, in the lineal ratio of the circumference of the loop or wave to its chord.*

a. It will be observed in 170 art., in the case of a compressed wire in the groove, as also of a loop in a free rope, that for the wire to lie down quiescently in the groove or the rope upon the ground, after it is once compressed to form a loop, the point of compression being always supposed to remain rigid—that *space* for the loop in each case must be found *in front of it*, that is, on the side away from the impulse that causes the compression. So that for this lying down we require the possibility of a motion of displacement in the system equal to the lineal excess in the curvature of the loop over its direct chord. Therefore, upon this principle,

ant normal action of gravitation, free mobile matter
rgy to be permanently displaced by a compressible
the lineal ratio of its circumference to its chord.
onceive that the same principles as the above may
pplied to the compression of a liquid, for we may
pressile wave as being formed by an infinite series
ting within the other. In this case such loops would
ude to the plane of repose, yet theoretically as each
em possesses greater potential force in its centre by
ess of matter necessary for its curvature in excess
loop system, *its force of displacement would be equal
orm system.*

xperimental demonstrations of the principles here
I can offer, will be found in the beautiful experi-
hes of Mr. J. Scott Russell, in the form of liquid
termed a wave of translation; described in the
ion Reports for 1844, p. 319. In this, the pheno-
I here only suggest the principles, is ably discussed
mental particulars, to these I must refer the reader.
r, mention that the looped compressile wave is so
the altitude of the wave is maintained with little
eat distances, and the velocity remains constant for

near its two ends towards its central part; the paper being placed on a flat surface and the ends kept down with the hands.

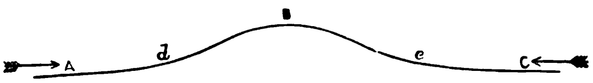


Fig. 185.—Conchoid produced by a Slip of Paper.

c. Applying the above principle to pressure upon a liquid surface; supposing gravitation uniform on the plane A to C, at first level, and that the compression is made in the direction of the arrow at A which is resisted by the plane extending to and beyond C, the whole surface system having a certain flexible rigidity as proposed for aqueous surface by the presence of extensile forces, 16 prop., page 45; then, by the pressure, the loop B would rise upon the part of the system that was at the time from any cause least able to resist it. Assume this pressure upon a part of an infinite surface A to C, there would then be external flexure at B, and internal flexure at the points *d* and *e* in the figure, where the force first deflects the adhesive flexible system. Such compound flexure would produce a conchoidal outline.

d. Assuming a pressure as a continuous direct moving force upon a liquid plane, its motive elements of equilibrium may be taken in the following manner, as shown in the diagram, Fig. 186, below.

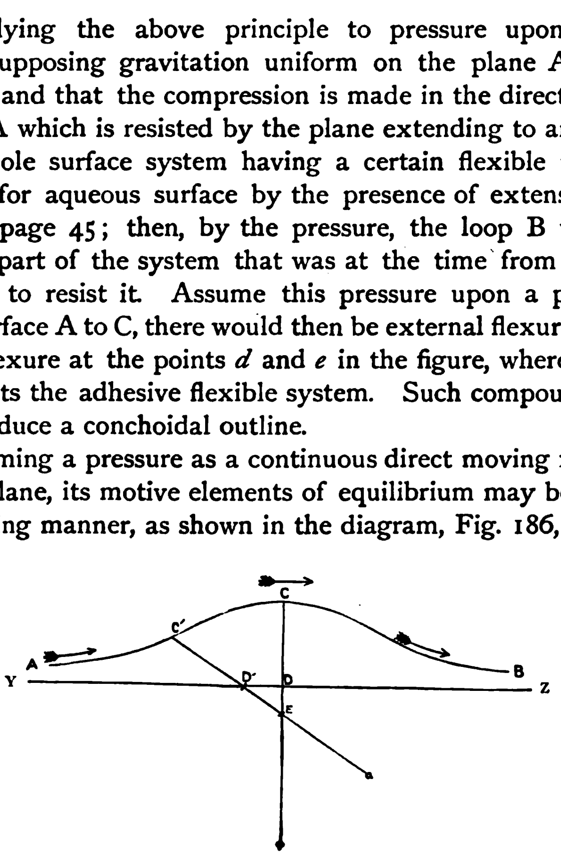


Fig. 186.—Diagram—Generation of a Conchoidal Wave.

Let the line Y Z represent a part of the section of a level liquid surface of infinite extent. Let a horizontal pressure beyond the figure to the left hand elevate the conchoid A C B above the plane of repose; and this pressure be such as will elevate the axis C D of the liquid conchoid for the distance C D, in the time that the

by cohesion the surface below Y Z upon an axis
se depth is equal to D E. Assume E the centre of
from this action. Then, supposing the system
le, the potential represented by the gravitation forces
plane of repose Y D Z will be equal to the pressure
ses the elevation of the wave; and as all pressures
n of horizontal impulse and gravitation will be
ds E in the elevation of the wave, they may be
every place upon the plane of equilibrium Y Z by
in radial direction from the axis of rolling contact,
if the point E be taken as a fixed centre, and the
ius C D, as the edge of a free straight rod, be moved
e of repose represented by the line Y Z keeping the
ntly on the line; the end of the rod C will describe a
l wave engendered by a horizontal pressure equal to
potential of C D to the plane of repose Y Z. This
one position at C′ D′ E. It will be noticed that the
n the point E, therefore the radius D E may be
present in magnitude and direction the inertia-resist-
impulse, which constantly increases as the angle de-
plane of surface equilibrium. The ratio of this
the power of the horizontal force to deflect the

the conchoid of Nicomedes, described in *Nicholson's Five Orders of Architecture*, which is said to be the most simple means known of describing the contour of a Grecian column. This instrument is shown in perspective in the engraving, Fig. 187, describing an inner line. It was drawn for illustrating other matter.[1]

f. The conchoidal wave form may be described on a line with a straight slip of paper having the distance C to D, Fig. 186, marked near one end, keeping the straight edge of the paper E and the point D on the horizontal line Y, Z.

g. It may be seen that the proposition relates to a free wave only, so far as this is strictly compressile, the compression not being in excess of that capable of forming a *conchoidal system.* It will be seen further on that with greater compression the force of gravitation in higher waves acts otherwise upon the wave system, and permits certain parts of the compressed water to fall away from the most elevated part, as free matter until the conchoidal system alone remains active.

Velocity of propagation of protuberant waves in looped systems.

175. PROPOSITION: *That the velocity of a single free compressile wave moving in a horizontal uniform channel upon a surface of liquid at rest, will vary directly as the distance of its parts from the plane of support for the whole depth of the liquid; such parts being taken to be moving by rolling contact upon free axes or radii extending to the bottom of the channel; the velocities being in proportion to the force of gravitation acting tangentially to the radii the parts subtend to the axis of resistance.*

a. From the observations of Mr. J. Scott Russell we find that the velocity of a liquid compressile wave moving in a parallel horizontal channel is equal to a free body falling by gravitation half the depth of the liquid from the crown of the wave to the surface of resistance. By the principles of rolling contact of fluids (44 prop. *b*), the point of contact of a liquid on a plane in relation to any higher point, is as a radius of a free lever upon a fulcrum of resistance; so that tangential velocities are as the forces active on the free parts of the lever. The protuberance of a compressile wave as an infinitely mobile system in unstable equilibrium will be free to act by sequential n, 171 prop. *b*, to the influence of gravitation. Upon ns the velocity of a free compressile wave of the whole channel, neglecting its conchoidal outline by taking a vertical to its crown only, may be resolved as follows:—

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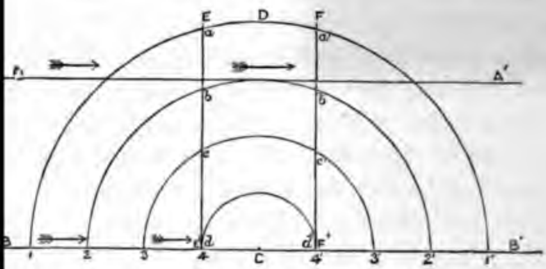
[1] *Treatise on Drawing Instruments.*



gram.—Equilibrium of a Liquid in a Parallel Channel moved by a Vertical Part.

Fig. 188, be the top of a liquid surface resting in perfect n B B′, the bottom of a parallel channel.

any point of resistance vertically below the greatest of the compressile wave, whose summit is here shown

micircular arcs 1 to 1′, 2 to 2′, 3 to 3′, and 4 to 4′ resures in equilibrium, radial about the point C. The

F F′. Then will the radial velocities of vertical parts moving upon the point C as a fulcrum be resisted with the greatest force at *a′*, as the excess of this radius over other vertical parts will the sooner meet the resistant plane F F′. At *b b′* the radial velocity will be less than the above, but its radius of arc and therefore its freedom will be greater, as the resistance of the plane F F′ will be less immediately active. At *c c′* the radial velocity will be again less, but the resistance of arc also less. At *d d′* less again, this now forming a complete semicircle. Therefore forces impressed in a horizontal direction by the vertical, E E′ will move forward through the space included between the arcs, considered infinitely small of E E′ F F′ by equal effective horizontal displacements, as the restraint at different parts of this parallel space will be proportional at different depths to the radial velocities at the same depths. The entire velocity will therefore be in equation with the average horizontal velocities of the separate parts, and if this be from the action of gravitation acting normal to the system, as here assumed, it may be represented as the tangential action of free gravitation upon half the radial distance of the depth of the liquid, and irrespective of the surface curvature, if this is not great, at the point taken.

d. From experiments in respect to the absolute velocity of the compressile wave agreeing nearly with the above, as shown in the beautiful experiments of Mr. J. Scott Russell, I conclude that water must be a cohesive fluid with little viscosity, as it appears in these experiments, to move subject to its inertia alone.

e. To prevent misunderstanding I may note that if the liquid compressile wave be moved by a force impressed at the *surface only*, as by the wind, the restraint of resistance will be constantly as the radius of the depth affected, and equal to the surface resistances at F for every radius to which the liquid moves by its cohesion. The velocity of the compressile free surface wave in this case will be at its surface, but half that given above for the same depth of liquid moved. Further, the system of the compressile wave will not be in equilibrium to move as a looped system, but under restraint of the lower more inactive parts, there being no free radial velocities as in the case taken for movement of a vertical plane from E E′ to F F of the whole depth of the liquid, it will therefore soon come to a state of rest and subside, unless constantly maintained by an exterior force. There are also other conditions affecting the velocity which I will hereafter consider.

waves. Surface movement under cohesive eeper water.

TION: *If a surface stratum of water be projected by over quiescent or oppositely moving water, the surface ke intermittent rolling contact upon the water beneath protuberances or waves into the air.*

conditions may be those of the inflow of a river e opening of a sluice, the overflow of a weir upon sive surface, or an undercurrent moving in opposition otion. In regions where oceanic undercurrents are ted to the surface currents we have the most stormy eastward of the Cape of Good Hope, and Cape Horn.

b. It will be convenient to discuss this proposition for a single unit projection upon a liquid surface plane in which the motive unit may be considered to move *tangentially* against the resistance by inertia and cohesion of the mass beneath; the whole system of the liquid being held in horizontal position by a *radial force,* namely, that of gravitation.

first to a point *d'*; then a further effort of the tangential force moving a backward part again *d* to *e* would deflect *d'* to *e'*, and in like manner *e* to *f*, and *f* to *g*, and these movements would constantly disturb a greater depth of the liquid, say consecutively to the points *d'*, *e'*, *f'*, and *g'*, assuming the tangential force to affect a depth proportional to the horizontal displacement.

d. In the above diagram the vertical series of molecules is represented free, it would therefore in following the deflection of the single molecule meet with constantly more and more resistance as the deflection became greater, assuming it surrounded by like fluid. It would also meet with more resistance by the deeper displacement of the longer series of molecules. Further, the tangential force imagined, is directly tangential to the first static position of the molecular series only; so that as the deflection of the first molecule of the series becomes greater the tangential force upon the vertical series of particles becomes less by this displacement, so that at a certain point of deflection in this single series of molecules we can imagine the first particles moved to be brought vertical to the original plane of projection.

e. We may now consider the conditions of a single particle upon a continuous cohesive surface in which the particle is not free as in the last case, other conditions remaining the same. We will in this case suppose a tangential force constantly active on a *selected* surface molecule *only*, as before. In this the surface molecule being deflected, another molecule will come forward by the general surface cohesion and take its place, and another in like manner, so that each molecule will be deflected by the tangential force above it, and the next molecule that moves forward, equally so, and the next, and so on. Now as we assume that each of these molecules is moved to a greater deflection with respect to the forward surface, then as all surface parts of the liquid follow in like order, it is apparent that these *sets of deflection* from the surface will form motive directions

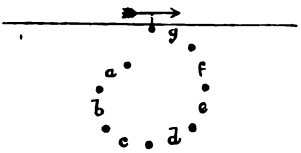


Fig. 190.—Diagram—Theoretical Continuity of Tangential Impulse.

w each other as constant efforts of the same continu-
action, and the molecular displacement will circum-
point below the liquid surface; so that for the small
consecutive tangential actions upon the molecule
ically represented by the diagram, Fig. 190.
it to the left of *g* be a surface position taken, and
onsecutive particles moved, then the angle of deflec-
osition being set for a small unit of time by the de-
first movement of each particle; the deflected parts
ly lengthened in lineal series would cause them to
inuity of like deflection to the position from which
as first moved, and the whole would complete a *circle*
ion of the first displaced molecule. If we further as-
resistance upon the system this would induce a further
for deflection, which would give a spiral direction to
lecules taken.
in refer this system to that illustrated, Fig. 189, we
surface particle were deflected in a circle of a certain
nd particle below must be deflected to a less radius
ng force would be less; and further, as the assumed
ial impulse act continuously upon the cohesive system,
eflection occurs in a certain time, the whole movement

the mass moved. Its power to impress force in the water beneath being derived from adhesion only.

g. The above conditions of surface motion presuppose the possibility of a surface plane entering the bulk of the water which is not evident by experiment; we have, therefore, to consider further conditions.

h. By the principles of rolling contact, a fluid rolls upon a surface of resistance, 45 prop. The same must occur by horizontal force movements of a liquid surface on the unmoved or resting liquid beneath, except that the assumed deeper surface, in this last case, is not a fixed or definite plane, but a hydrostatic plane which reacts upon any force impressed within by its own elasticity.

i. The action of a superficial horizontal motion upon a liquid surface may therefore be taken, by greater refinement, in the following manner for the displacement of a surface particle.

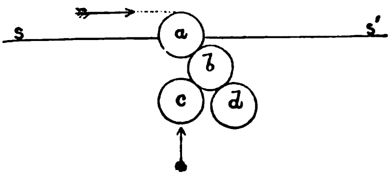
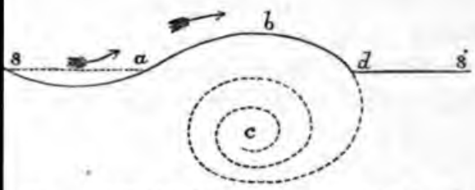


Fig. 192.—Diagram—Riding Action of a Surface Molecule under Tangential Displacement.

Let S S', Fig. 192, be a plane of repose and *a*, *b*, *c*, three particles resting at first in the plane before the impression of the horizontal force shown by the arrow. Suppose the motion to extend at first to the depth of one particle only as before taken (Fig. 190). Let *d* be the first particle deflected, *b* the second, moving on *c*, and *a* the third. Then, as this series of deflections would move towards the resistance of the liquid beneath, and the aerial space above the liquid surface would be free from this resistance, the particle *a* would rise into the air by the resistance of the inertia of *b* and *c*, and be protruded above the surface with a part of the horizontal force with which it was at first impressed.

j. If we now summarize the conditions of active tangential forces upon a deeper position of repose, we find that by conditions here proposed, §§ *c*, *d*, *e*, and *h*, that the tangential action would be such as to produce a *whirl*. But that by the conditions proposed, § *f*, such a whirl would be perfectly free at the liquid surface plane, and under greater restraint, proportionally to the depth, at greater depths.

he whole we may assume by composition of such
the separate conditions proposed, that the whirl
e excess of water in motion at the aerial surface
be constantly induced to *lop or tumble* over in alter-
manner which will somewhat resemble the motion
ody in walking, wherein the foot at each step forms
ion. The cramped form of whirl induced to secure
may be theoretically represented as in the engraving
except that the motion will be largely impressed by
lses and not by entire displacement of the liquid parts.



—Theoretical Whirl Deflection under Tangential Action of a Liquid Surface.

epose S S′, moved by a horizontal force in the direc-
he arrows, raises a protuberance at *b*, and continues
f tangential velocities of the cohesive system by

action, as a form of incipient biwhirl whose cone of impression is at *d* to *e*.

l. The amplitudes of tangential waves are proportional to the velocities of the overflowing force which induces the lopping

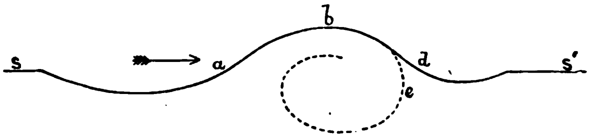


Fig. 194.—Diagram—Surface Equilibrium under Whirl Deflection.

action, a greater velocity engendering a broader wave, the tangential forces carrying direct impulse and suffering deflection inversely proportional to the constant force of cohesion of the liquid which induces the tangential deflection to form the protuberance.

m. If the tangential action be derived from a single impulse, as in water overflowing a weir, the first wave will be broad, being produced by direct tangential action upon the surface; another wave will be produced after bifurcation of the force at *c*, *d*, by the remaining tangential impulse of the surface deflection only *d*; therefore the second wave will be less, and a third again, by continuity of decrement, proportionally less, by like action. Waves upon the principles discussed may retain local positions upon the surface, or be carried forward by motions of general displacement of the system in motive composition.

Action of wind upon the surface of water.

177. PROPOSITION: *That the retardation of moving air by the adhesive resistance of a still surface of water and the greater freedom from resistance at any position above the surface, will cause each molecule or small part of the air to rotate towards the surface of resistance in such a manner that the result of its impact upon the water will not necessarily move the surface in the direction of impression.*

a. If there are present two unequal lateral resistances to the projection of a free particle or mass of matter, the greater resistance will retard the projection the most, and the particle or mass projected will rotate upon its centre of inertia over towards the greater resistance. This is shown in that the resistance of a moving fluid is greatest near a solid or other more resistant system of matter, sistance will decrease in a certain constant ratio to istant plane. So that from this cause a fluid passing ll have parallels of velocities that will be unequal, we assume the fluid to be air passing over water, ear the surface may be conceived to be placed lanes having different velocities, the greatest being rthest from the liquid surface; the absolute surface ively quiescent to the motion. Taken in this manner a certain stratum of air above the water would be er side of the particle forward with its own velocity, he under side of the particle where it was more pard by the resistance of the static water near, would nce have less velocity. Therefore, the particle would evolution upon its own axis of inertia as a resultant s of the two parallel forces of unequal velocity, as idered for rolling forces, 46 prop. *b*.

v consider this particle to be pressed forward and continuous elastic force of compression behind, so that rticle of a strong wind. It would then impinge upon vave that under the circumstances would be inclined this it would impress the resultant of all its motive although by its entire initial velocity it might have (*a*) The motive stratum farthest from the surface of resistance in the water below, not shown in the engraving, therefore, that of highest velocity affecting the motion of the particle A.

(*a*′) Stratum of greater resistance nearer the resistant surface and therefore of less velocity than *a*, the particle A, Fig. 195, is therefore turned in the direction shown by the arrow in front of it. In Fig. 195*a* the same particle of air is shown striking the surface B′. Under such conditions it ejects the water in the direction of its revolution, as shown by the arrow below.

c. If in the above cases the forces are assumed to be direct, and no principles of whirl motions are taken to be induced in the general system, the velocity of revolution of the particle will be slow; but if the lineal pressure A or B deflect the particle, as well as cause it to rotate, the revolution to follow the whirl current will be quicker. The principle induced by the movement of a particle in rotation impinging upon a surface of repose, may be roughly shown by giving a hoop a motion of rotation, and at the same time projecting it to a certain distance upon the ground; in which case the rotation will not interfere with the general projection, but will after contact accelerate or reverse its projection by friction upon the surface of impact, so that the hoop when the rotation is in one direction will have its velocity increased upon contact with the ground, or in the other direction it may roll back to the point from which it was projected. In this case, nevertheless, the revolution in the hoop in no way neutralizes the projectile force, which makes its percussion on the matter opposing its direct projection exactly as though it possessed no initial revolution; except the action upon the surface of contact just stated.

d. By the principles of rolling contact in fluids, to which I am compelled so constantly to return in demonstration of every motion of one fluid acting upon another; we find that in the case of air moving upon water, by the adhesion of these two fluids, assuming as I propose that there is no slipping motion, the air will necessarily have the velocity of its surface of contact with the water reduced to the surface motion of the water whatever this velocity may be, and in whatever direction it may take. The effects of this adhesion upon motive air may extend by a decreasing series of velocities for a great or small distance, according to the velocity or pressure of the aerial force, whether it has power to break or bend the cohesive system of the air more or less near the surface of the water. If we

tion of this adhesion as producing a reflex surface
auses discussed, at the aerial aqueous surface, the
l then return by deflection in opposition to the direc-
projection by the principles of rolling contact. We
e that in this motion there will be the same forms of
extending forward to the more static water surface
in (88 prop. *e*, Fig 121, page 249), so that absolute
demonstrated for water will occur in this case in the
water, by its superior density, forms the resisting

deavoured to show that this is true experimentally,
cceeded by any striking experiment. However, the
aid our conception a little. If we cautiously and
oke upon water, the smoke being heavier than the
ly advance upon the water. I have noticed in this
ead of the projected smoke curves at the water sur-
pparently only a slow motion of revolution of which

178. PROPOSITION: *That the effect of the impression of an oblique impulse by air on water will be to extend the liquid surface to greater area with disturbance of the equilibrium of the static extensile state of the liquid surface; thereby producing ripples.*

a. The general principles of surface extensibility were discussed, 16 to 23 props., and of motive continuity of extensile surface strains 24 prop. The conditions under which aerial impact becomes oblique were discussed in the last proposition. The experimental evidence of the proposition may possibly be seen in every puff of wind that disturbs a still surface of water.

b. It is presumable that if an aerial current were of perfectly uniform velocity in all its parts, that its impression upon a surface of water, in perfect equilibrium to gravitation, would not ruffle the surface, but by the principles of rolling contact there would necessarily be separation of the air into motive units. This separation is also evident actually in the motion of air over any object in sensitive equilibrium, as a blade of grass, which does not bend simply to a curve under the wind action, but *dances* also in it. So that it occurs from the sensitive state of equilibrium of water, its tendency to surface extensibility (16 prop.) and from deflected impulses of impression, that actually its surface is always thrown into ripples by a wind active upon it, and these ripples are the first motive effects, which under continuity or increase of wind force, become waves.

179. PROPOSITION: *That in light winds over rippled water where motions of easy accommodation may be assumed to occur, the liquid surface will be impressed with hollows produced by lateral diffusional whirls of aerial projection.*

a. The principles of the above proposition were discussed for water, 105 prop., but the conditions now to be considered are changed by the liquid surface being one of partial restraint to the aerial motions from adhesion. The same principles applied to static surface were discussed in 109 *remarks*, page 319, wherein it was suggested that whirls would form in every indentation of surface (*d*) by the influence of *shading*. Upon the same principles when a surface of water has become ruffled by the wind by conditions of the previous proposition, every hollow upon such a surface is in relation to the horizontal elements of direction of the wind an area of repose from its action.

further seen that even if the surface of water is not
y intermittent force that there may be in the wind
e action (*b*, last prop.), would upon a resistant liquid
tact at once induce the surface to divide by the
thus form separate whirls which would be at first of
ns.

also conceive by the whirl system of motion in
ng against the more static resistance of water, that
resistance of one side of the plane of motion would
ent naturally by a retrograde movement (89 prop. *c*)
mediate surface of contact. Further, by the forma-
ssible whirl of contact in a free fluid, we have one of
ensured; either that the whirl must continually in-
ensions by the continuity of decreasing resistance
in which it is generated, or it must form a whirl over
and leave the remainder of the surface free, either
e current, or in a condition to form other like whirls.
appear from my experiments that when a larger or
ace occurs in the path of the most static side or
an increasing whirl would continuously revolve until
ce, even if it were the bay of an immense ocean, but
traint or inequality of resistance, whirl forms are at

permits the formation of waves, as the separate units of impulse are deflected by surface contact to form a system of whirls which occupy approximately equal interspaces upon the water surface. We may represent these conditions, as in the diagram, Fig. 197, consistent with the forms of rolling contact of air on the deflectable surface of water; either where hollows exist, or intermittent impulses are impressed from above.

e. In air passing solids, no planes of deflection could be formed in the solid, as in a liquid, and the adhesion of the air to the solid would possibly be less. But I have occasionally noticed the same principles of motion in drifting dust and snow, where a point of superior resistance occurs, so as to leave a more quiescent air space in front of this, equivalent to the hollow of a wave just considered. In this case the current of air moves continuously, and the deflection occurs at a certain point where a whirl is produced by the overcurrent nipping up a surface wave. This is shown by the direction of the arrows in the diagram below.

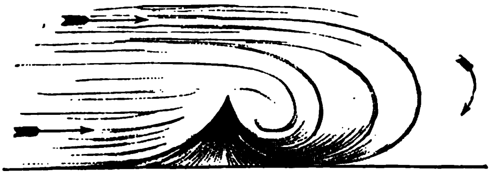


Fig. 198.—Ex.—Dust Wave formed by Wind.

f. The above described form of motion is very frequently caused by the interference of a wall or tree, but I have seen it often occur in simply undulating ground, or irregular solid surface, and observed it in the drifting of autumn leaves along a high road.

g. The whirl resistance under the above conditions still remains in the line of direct, or tangential impulse, of the whirl. It is uniformly greatest upon the back of the wave, where the greatest freedom from interference also occurs; so that the dust heap, leaves, and ripples we have considered maintain a general projectile force in the direction of the wind.

h. What we find important in this matter for the consideration of vertical whirl-force, in the free motions of the wind, so far as regards a liquid surface, is that wind may appear to produce a *retrograde motion,* and will do so naturally on the back of the wave. Therefore if the surface of the ocean did not ile force from the wind, the surface motion would be its direction. That this is not really the case under I will discuss in the next proposition.

observe in the action of whirl motions generally in rl is produced by a tangential impulse moving a free about a centre of inertia, therefore that its motive is cause uniformly *circular*, and take no other form, d from it by restraint (83 prop.). Therefore the inter- of separate units of air in the wind upon the relatively es of repose formed by the hollows of the waves, will rl motions induced to *constantly correct the form of into semicircular hollows.* Wherein the waves differ the influences of other causes that I have already ompressile forces, and will further consider.

SITION: *That the projectile force of the wind acting ive surface of deep water, if it exceed the velocity of easy for rolling contact, will drive forward the aqueous velocity of displacement which will be according to the t upon the surface and the momentum of the wind's ohesion of the water at the horizontal plane; the hollow* *b.* The principles of the above may be expressed diagrammatically as follows, taking three cases, of which the last only accords with the conditions of the proposition.

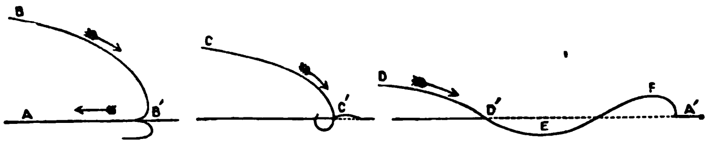


Fig. 199. Fig. 200. Fig. 201.

Diagrams of Aerial Impact on Water.

Let the space included between A and A', extending through the three diagrams, be a liquid surface in equilibrium.

B B', Fig. 199, will then represent the direction of motion of perfect accommodation by rolling contact of air; in this case, moving nearly frictionless upon the liquid.

C C', Fig. 200, represents *deflection* of the surface of the water, so that the air in this case impinges perpendicularly to the surface, causing thereby greater instability of surface equilibrium, and some forward compression at C'.

D D', Fig. 201, represents a higher velocity of the wind by the magnitude of the momentum to the small relative resistance by cohesion to the aqueous surface, the whirl taking a sharp parabolic form practically meets the surface at a less angle. In this case the water has a tendency to be projected from the surface in front of the point of impact, D', and by deflection upon the mass resistance from E to F.

c. In the above diagrams, to complete the theoretical forms, I take the motion of single units of projection as before, and assume no interference. It is quite certain that this could not happen in a perfectly uniform moving wind if such a phenomenon exists. The principles here discussed show, that upon aqueous surface there will be very small resistance to gentle motions of the air, but great resistance to intense motions, and less surface stability under more intense wind forces.

d. Upon principles shown in diagram, Fig. 201, the impact of air in the direction D D' by the action of which a hollow is scooped out, and a protuberance projected forward, we might conclude that the entire surface of a liquid impressed by such a local force, as that of a gust of wind on the ocean, would cause the water to be projected impulse. This is not evident by observation of the water, but that this action is actual, appears to be ed by observing the manner in which the wind drives c waves; for we are certain that if a hollow and forming a wave are brought into existence by ng upon a surface previously in equilibrium, that ıst be first *scooped out* to form the protuberance, ping could only occur behind the protuberance. protuberance is formed from the liquid *pressed for-* e hollow. Upon this principle we may conceive the d to be urged forward over the whole surface, by ke action, in pressing forward other parts of the sur- as the separate units of the breadth of the wave are ough the deflection of contact resistance gives an im- e reflection to the direction of projection (179 prop.), f water will be urged forward by the general hori- um of the entire initial force of the wind.

ITION: *That a steady wind over wavy oceanic surface ittent in its action upon waves by impressing alternate nore than alternate shadings.*

l having once raised a wavy surface upon a wide when exposed to it. In this manner, as each wave is followed by an interval, before the wind-force can again be active to produce another impression, the motion induced in the backward parts of a ruffled system will be carried forward constantly by the now intermittent tangential action of the wind upon it.

c. To follow each separate wave according to these conditions, the following construction may be taken.

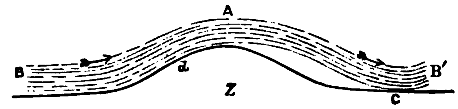


Fig. 202.—Diagram—Intermittent Action of Wind upon a Wavy Surface.

Let Z, Fig. 202, represent a single wave, and assume this wave to be formed by a tangential compression by the lower atmospheric stratum represented by B B′ moving in the direction indicated by the arrows, and let this impress the wave at the salient angle formed by its plane, *d.* Then will the assumed horizontal projection of the wind be deflected by continuity as a compression upwards at A, and its elastic momentum will not impinge again actively on the liquid surface until it reaches C, where, by its impulse, another wave will be formed as a secondary resultant of continuity of projection of the wind.

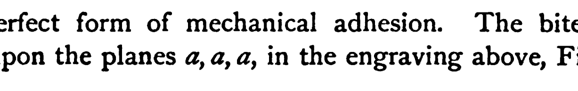


Fig. 203.—Diagram—Waves of Easy Accommodation.

d. The continuity of bite of the wind upon the surface of the rippled ocean, which produces larger waves, may not inappropriately be compared to the bite of the threads of a screw which produces a very perfect form of mechanical adhesion. The bite will be greatest upon the planes *a, a, a,* in the engraving above, Fig. 203.

Conditions of division of a liquid surface into waves by tangential compression.

182. PROPOSITION: *That a horizontal, or tangential, force impressed in adherent matter upon the surface of a liquid will raise separate units of the liquid into protuberances by the resistance of the inertia* *arts of the liquid. These protuberances or waves will a gravitation potential of resistance in equilibrium tum of the tangential force impressed. By continuity angential forces will act cumulatively, so that the whole te units or waves will also be raised into larger pro- e manner.*

p. it is shown that every unit of a surface impressed forces is in unstable equilibrium, which induces override the other and thereby produce surface would occur, of course, more easily under the inter- of the wind, and by this motion the conditions of water become of the same form, as before discussed, urface displacement in 175 prop.

nditions of surface division into many waves by the angential force at or near the surface may also be shown, for a simple case, by moving a small body lly with moderate velocity at a small depth in the ater. In front of the moving body a series of small surface waves will be formed by the compression (24 quid surface, in this case, will appear to be *crumpled* ciple may possibly at all times be active in the for- larger natural division of an extensive surface into to cause a compressile wave will by continuity of pressure, where the wave is raised to a more salient angle to the wind's impulse, cause its maintenance during the continuity of the impression. It is also clear that if this salient angle be once produced, that a greater force in the wind will exert a greater pressure and the surface will tend to expand upon the compressile wave. This increase will be proportional to the force of the wind since the wave increases in height as the horizontal forces press it forward. It increases also in area of base as the constant force of gravitation brings the figure of the protuberance to equilibrium as a conchoidal system, so that at a certain point of elevation and expansion of base, the tangential pressure by its momentum will come to equilibrium with the potential of the elevated wave, the inertia of its mass, and the force of cohesion of the liquid system combined; and it will rise no more. As one wave is formed so will others be, until the aqueous surface is covered by waves of dimensions proportional to the extent of pressures into the resistances.

183. PROPOSITION: *If by the contiguity of solid matter to a wave system the area over which the resistance is carried be confined, or the tangential force of the wind act with great intensity over small area, the liquid surface will be more compressed, rise higher, and flow less easily to a state of equilibrium, so that sudden forces impressed upon small areas and resistances to surface forces by solids, will produce relatively higher waves of smaller base.*

a. This is seen in a wave running inshore, where the resistance of the shore causes it to rise and break. Also by restraint of coastline as for instance the broad Atlantic wave becomes a shorter and higher wave in the Bay of Biscay.

b. The evidence of the above may also be clearly observed by looking over the daily weather reports issued from the British Meteorological Office, wherein we find the direction of wind upon a coast generally produces a rough sea, which is caused by the volume of the wave being *shortened* up and the surface pressed together by the resistance of the coast to the inflowing more free conchoidal wave engendered at a distance from the coast by the wind. It is possible that the entire momentum of the wind by its adhesion may be generally found in the potential of the water elevated by it above the surface of equilibrium, over the whole areas of resistance.

waves are produced by strong winds and ripples by re is no doubt that a certain ratio exists between the and the force of the wind, for a constant wind acting e surface agitated by no currents. But the difficulties tal investigation are immense, as wind forces act to a certain extent on the volume of the wave, every e surface of a large wave being subject to exactly ressions and re-divisions as a level surface if struck at e.

general assurance of the fact of pressing up of surface wind's force, observations of the most superficial kind the forward elevation of the oceanic surface is abso- is cause, and that no principle of mere oscillation of ollows will answer to experience. It is well known served that the wind blowing towards a coast or up s the sea with it and elevates the water much above vel. That setting from the coast or down the river it ters outwards. We cannot in these cases infer that nce of the water is in any way effected except by e wind; neither can we imagine that the deeper parts re greatly disturbed by the exterior tangential action therefore the actual displacement must be by surface where the equivalent wave would be urged forward as a looped system of compression.

e. Upon the principles here discussed the diagram, Fig. 204, may represent theoretically the action of a storm in the open ocean, the area of resistance being at A′ which may be either the resistance of quiescent or oppositely directed water, or of a coast.

Let A A′ represent by a line the plane of static gravitation equilibrium. The two arrows above, A B B′, represent the direction of the wind. The dotted line below the extent of the return current, showing possibly the depth of water affected by the surface movement within the amplitude to the wavy surface.

B B′ represents a great wave, which does not divide by its relative amount of elevation simply, but by the resistance to its impulse. In the open sea a wave divides when its elevation becomes greater than a certain function of the radius of the depth of water moving in the same direction in the wave system, probably when the depth is less than double the elevation of the wave above the plane of lowest motion of the system. The wave probably breaks more readily at the front of the storm B′, than at the back B, from conditions I will show in the next chapter.

f. If a storm be directed upon a coast, the coast resistance is felt for a long distance outwards from the land, so that the storm compression, at its greatest surface elevation, seldom or never reaches the coast. This is assumed by principles of conic resistance to liquid projections in flowing forces (88 prop.), there being always in the case of a storm impinging upon a coast an area of compressed surface, where the waves rise much above the figure of conchoidal equilibrium, the sum of the compressile force being largely lost in the separate potentials of the elevated crests (171 prop.).

g. Open oceanic compressile systems are increased in elevation by the impulse of the tide coinciding with that of the wind. The tides forming otherwise naturally compressile systems by the effects of tangential attraction of the sun and moon upon the oceanic mass.

CHAPTER XVI.

GRAVITATION UPON LIQUID PROTUBERANCES OR WHEREIN EQUILIBRIUM IS RESTORED BY SURFACE IONS. CONDITIONS OF HOLLOWS—OSCILLATORY —AND GENERAL COMBINATION OF FORCES IN WAVE MOTIONS. CURRENT WAVES.

Compression—Hollows.

mencement of the last chapter, 170 prop. *g*, a general s made that wave motions occur from two causes,

Infraction of liquid surface.

185. PROPOSITION: *That if a motive impulse be impressed upon one part of a lineal homogeneous system in a direction to produce greater extension of a part of the system, than the general cohesive force can withhold by the traction of following contiguous parts, this impulse will cause a fracture which will release the motive part from its previous cohesion to the mass system. The fracture formed in this case will be normal to the direction of the force, and occur at the weakest part of the system behind the moving part. On a liquid surface under the like conditions of extension, a partial fracture only will occur.*

a. If we fracture in a long solid body of uniform section by a longitudinal strain, the fracture will occur at a point in the solid where the molecular force of cohesion is weakest, and this will be consequently the first part to give way under the strain. With a liquid, where every part is mobile, a like point of least resistance occurs only insipiently, as the general cohesion of the system may be assumed to cause the fractured parts instantly to reunite after the release of the strain. Therefore a liquid, by a kind of mobile equalization of strain, causes the parts disturbed by the strain to move consecutively from place to place until equilibrium is restored; so that a plane of fracture or *infraction*, as I term it, in a liquid, may be one that exists only for an infinitely short space of time, in any single local position. This form of fracture being necessarily at no period entire, as in the case of fracture of a lineal solid, where perfect detachment is possible.

b. This matter may be made clearer by reference to more particular instances of the fracture of solids under strains equivalent as far as possible to those I wish to demonstrate for liquids.

c. If we stretch a length of metal rod or wire, we can imagine that every molecule forming this rod will experience a *strain* against the cohesive force by which it is held to the next molecule in lineal series of parts, all molecules being united in a manner to form a mass system. If we continue to stretch the rod it finally breaks, and the matter in the two separate parts is now again thrown outwardly into the same material condition of static equilibrium as the whole was before commencing the stretching, and each of the two separate pieces forms thus a distinct although similar mass system.

amine further into the molecular or physical condition fore the fracture, we find that the separation occurred *weakest point* of the system. We may also conclude d had been weakened at any other point, at this point ould have occurred a *plane of fracture*. Therefore a s system gives way or separates by a tensile force that disunite it, in *one plane only*, which plane will be that t transverse area normal to the lineal direction of the although all or many other parts may be nearly as , and may be affected during the impression of the in by tension in a degree almost sufficient to separate s parts, yet if the strain be within the range of the he material body, no outward physical effect may be or visibly produced and the system will generally rially considered, as at first.

another instance of the fracture of solid matter which dered relative to our subject—we may observe a surand broken away by the action of the sea, so that a cliff on the sea front. Gravitation is acting with great force le extent of this land which is unsupported by other ating matter on the exposed front, and if it were not for ohesive or attractive forces existing within the separate tions, for if there were liquid-slips these would be unlike the land-slips, as they would not be able to withhold, as it were, the cohesive force until cumulative strains fractured a particular part; but all parts would be *equally weak* and would move down exactly at that point where gravitation was in equation with the cohesive force of the system. Therefore, under these conditions, the liquid would move down by gravitation if unsupported on the side of each hollow, by a constant *disintegration in infinitely thin mass fractures*, or as I will term it, by continuous *infractions*.

g. The system of motion here proposed for liquids slipping down into hollows, has been given as a part of the cause of wave motions by M. Flaubergues—to which I will return further on. I may here remark that although I use the term *infraction* and *slipping* in the above case, this is really an apparent effect only (prop. 43, *e*), the motion being one of rolling-contact; but as a regular hollow plane is nearly produced, it may be taken as a slipping motion until further refinements are offered.

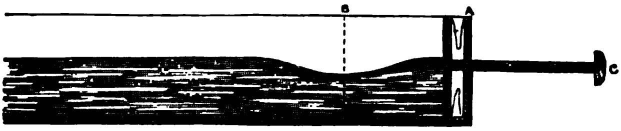


Fig. 205.—Ex.—Hollow Produced upon a Liquid Surface.

h. The infraction of liquids under the above conditions may be illustrated by taking the same long trough as described, 171 prop. *h;* this being partly filled with water and the false end being at the place it was left in the experiment, before described; that is, at the position B in the above illustration, Fig. 205. If we now suddenly withdraw the movable part from the position B, by the plunger C, to near the end of the trough, as shown in the engraving, the water will instantly form a surface hollow at about the position formerly occupied by the false end, as shown above under B. In this experiment, after the hollow in the surface of the water is formed, the water does not immediately slide down for a great distance or move gradually into this hollow by an inclined plane of motion, as might possibly be imagined upon principles of equality in fluid pressures under sliding motions, but it consecutively *breaks away* from the level surface as in the case of the land-slip just discussed, so that the hollow moves forward upon the liquid surface in equilibrium apparently by *con-*

ely small slips until it reaches the limit of the extent
surface. These slips are for the instant planes of
I term them—*planes of infraction.*

ve case there are subsidiary phenomena; for instance,
not fall into the hollow exactly as the land-slip, a
s; but by its fluid mobility, elasticity and mode of
, it falls as an *active* force, which produces a rebound
it to nearly the same height on the opposite side of
ce; so that the hollow goes forward upon the liquid
rue wave would. The reflected slips fall again con-
similarly to the first, as they reach the same altitude,
llow is followed by another engendered upon exactly
ciples as the first, and this by another until a wavy
duced. To the more exact condition of this process

ove there are also subsidiary effects which disturb
rinciple offered. The falling mass of the infracted
to the surface of the forward parts of the hollow
falls, so that it never absolutely *breaks*, but the entire
rs as a regular systematic transference of a minus
epresented by the hollow, to areas of greater hydro-
to establish equilibrium. Further, each wave becomes

l. If there were no point of pressure *z*, to the left of the figure the plane of infraction would surround the hollow and the fracture would be equal on every side, but as this would produce residuary phenomena which would need our separate consideration, I therefore give the conditions of a hollow infracted on one side, in a parallel system, as the simplest case for primary consideration.

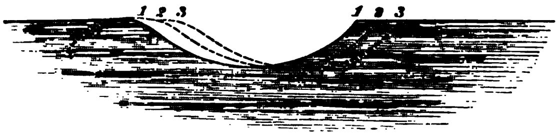


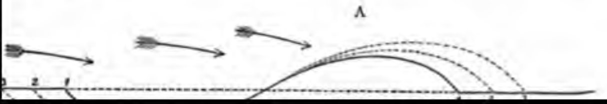
Fig. 207.—Diagram—Infraction Curve on a Liquid Surface.

m. Actually, by extensibility of surface (16 prop.) and the necessity for rolling contact of the motive parts of the system, the edges of the hollows are rounded off particularly on the following side, and in so far, do not resemble fractures. The surface adhesion of the separated water, and its momentum under deflection from a direct path, forms on the back of the wave an incipient compressile system (176 prop.) as shown by the continuity of curve 1 to 1, 2 to 2, 3 to 3, Fig. 207. The wave falling from right to left as in the previous illustration, Fig. 206.

186. PROPOSITION: *That large waves upon an extensive surface of water will grow larger by more intense wind force and will extend themselves over a much greater area than the region on which they were produced, by mobile compressions going forward over surfaces in relative equilibrium and infractions going backwards in like manner.*

a. The conditions of forward pressures producing large waves were discussed, 183 prop. The hollow also increases in the wave by infractions on the backward parts. The height to which waves rise in a storm is not from the effects of the average pressure of the wind over the area affected, but is in proportion to the intensity with which a local tangential compression in a unit of time elevates a certain mass against the general surface resistance (183 prop.). We may assume for the conditions of this proposition that an elevated wave mass exists, and that its protuberance is continually supported by the direction of the wind on its backward side, it will then approach in principle a free surface wave of the

discussed, 171 prop., but be moving upon a lower sur-
int; wherein the lower strata of the liquid will have
in proportion to the radius of depth affected by the
is case the loop or wave goes forward over a surface
n by a smaller constant wind force than that which
to raise it, and thereby continues its motion forward
locality where it received its original impulse. On
nd, by the principles of infraction discussed in the
on, the hollow will possess a power of propagation
te direction to that of the wind. This will be so,
the wind will aid the force of gravitation in breaking
ge of the hollow upon which it first comes in contact,
time that it supports the forward part of the hollow
ction. Therefore the entire action of the wind upon a
avy surface, once formed, will be to engender motion
ions: the one driving forward the protuberant wave by
ession, and the other breaking down the hollow against
of the wind. The above principles may be represented
ing diagram.



now nearly resemble Fig. 209 below which I have sketched from nature.

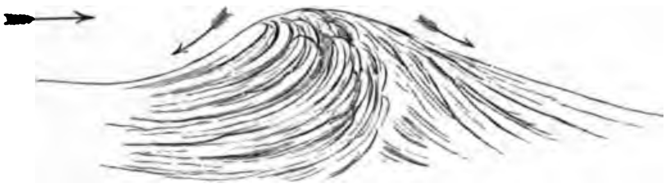


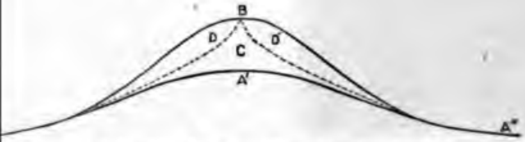
Fig. 209.—Ex.—Observed form of Wave.

d. By applying the conditions just proposed to the surface motions of a wavy sea—a wave being pressed forward by the wind at its back and infracted in front, there is found a constant tendency in the protuberance to override and fill up the forward hollow; at the same time the infraction is lowering the crest. In this manner also there is a constant tendency for a wave to extend its breadth. Further, as a wave at its complete formation, wherein its gravitation potential may represent the force of the wind (183 prop.), becomes immediately in a state of dissolution; so that the wave finally entirely subsides and forms the hollow of another wave, which is again pressed forward and infracted in like manner. These conditions are consistent with observation.

187. PROPOSITION: *A horizontal compression upon a liquid surface that acts too suddenly to enable it to produce a conchoidal wave, will produce at first a protuberance of central height in excess of the mass necessary to form a symmetrical conchoid; such protuberance, by its form being out of compressile equilibrium, will constantly fall away by infractions until the wave is reduced to a conchoid of compressile equilibrium.*

a. The conditions of a wave as a conchoid of compressile equilibrium are given in 174 prop. If a gust of wind impinge upon a conchoidal system, or a current in the ocean drive it against a coast, by the wave moving upon forward greater resistance than the open water, the surface system will be compressed, and its protuberance will exceed in central elevation a conchoid of equilibrium for a motive wave system (173 prop.), and in this case part of the protuberance will be immediately *infracted.*

lower line A A′ A″, Fig. 210, represent the outline of
vave in compressile equilibrium.



—Diagram—Infraction of a Wave when above Conchoidal Equilibrium.

vation B be engendered by a horizontal compression
of water greater than that possible in the time to
conchoidal wave of equilibrium A A′ A″. Now the
ce of the curved plane represented by A B A″ being
potential force by gravitation being great upon it;
be *infracted* by the conditions of 185 prop., and the
ction may then be represented by the lower dotted
nd B to A″, the excess of mass represented by D and
ht down to a lower position.

se the liquid in the inclosed space C would be at first
its base by the conchoid of equilibrium A A′ A″, but
of infractions the part C would also be brought down
oid only remain in motile equilibrium.

Division of large waves by Infractions.

188. PROPOSITION: *That any protuberance or wave upon a liquid surface that is not by its conchoidal form, a motive compressile wave, will through the action of gravitation upon it, be dissipated to gravitative equilibrium by infractions; such infractions from the vertex of the wave acting as biwhirl projections upon its lower parts, which represent the cone of impression to the biwhirl. By the biwhirl action there will be a constant tendency to redivision of the wave surface system, to restore gravitative equilibrium.*

a. The surface of water under the conditions of this proposition is assumed to be raised in waves or protuberances by some exterior horizontal or tangential compression, and gravitation alone is now assumed to be active in restoring such surface to equilibrium. In this case the mass of elevated water in the protuberant wave represents a potential force pressing upon the mobile system of the water beneath. This force embodied in liquid matter would clearly resemble the pressure by which a biwhirl is engendered (76 prop.), from the local pressure of a liquid of limited area being active upon a free more quiescent part; and we may suppose that the local pressure would now move against the conic resistance of the relatively static liquid beneath it by deflections, in the same manner as that shown experimentally in the case given, 77 prop. *e.*

b. The liquid impressing force would, by the above conditions, divide against the conic resistance of the mass beneath, and flow down both sides of the wave surfaces with the projectile force derived from its gravitative impulse. In this case, if its direction through the altitude of the wave, form a large angle to the horizon, it may cause the flowing water even to penetrate the quiescent base of the wave, as in the case of biwhirls in previous illustrations. If we represent the potential force of such a wave in a unit of matter located near A, as in the diagram, Fig. 211, then the biwhirl projection through gravitation would be representable by the whirls right and left, shown by the dotted lines, for the single wave under A;

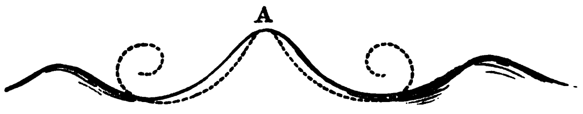


Fig. 211.—Diagram—Biwhirl Infraction of a Wave.

onic resistance being supported by the incompres- liquid beneath. The infraction of the surface would ntly dissolving the wave, but by the directive influence ls right and left, a new wave would be formed at its

pply the above principles to a wavy surface, the like es would be resident in every protuberance, and op- er in the contiguous hollows. Suppose that we have es, as represented in the diagram below, Fig. 212, then the wave A will be the same as the action of the he whirls derived from each of the biwhirl projections the interspace between the two as at B′, and in this

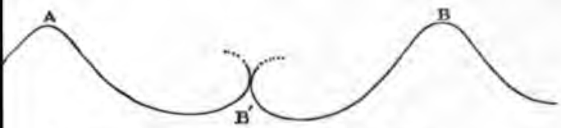


Fig. 212. Diagram—Biwhirl Formation of a Wave.

heir directive influences an intermediate wave will be n will rise in equation with the forces derived from s the action of molecular friction in the process of *e.* Experimental observation of the general action of gravitation upon the surface water of a wave may be made, I have found, at any time by a simple experiment as follows:—If we throw a few corks upon a rough or wavy sea the corks will be urged forward by the wave on its rising, but will retreat backwards on its falling, after the crown of the wave has passed the corks. This is more readily seen when watching two corks only, at a short distance apart in lineal range with the direction of impulse of the waves. These corks when on each side of the crest of the wave will move *from* each other, and when in the hollow move *towards* each other, by the same principles of surface infraction. These movements are represented by the corks moving in the direction of the arrows shown above the crest of a wave in the diagram below, Fig. 213.

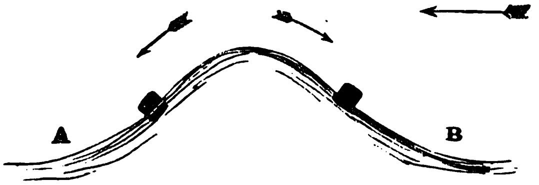


Fig. 213.—Ex.—Evidence of Infraction of Surface Water in High Waves.

Oscillatory Motions of Waves.

189. PROPOSITION: *If a hollow upon a liquid surface, surrounded by hydrostatic pressures, be more infracted by pressure on one side than on the other, the differences of such infractions or pressures will render the hollow locomotive in proportion to these differences, and the infracted water will produce a separate similar hollow or wave on the side where there is the least pressure. The velocity of waves formed in moving from the greatest pressure, or infraction, will be nearly equal to that of the swing of a free pendulum of a length from crest to crest of two such waves.*

a. By 185 prop., a hollow is propagated by infraction from a depression formed upon a surface of repose, and a series of waves are found to follow such hollow before the water can return to equilibrium. The surface plane in this case may be assumed to be an elevation of the liquid above the altitude of the hollow formed in the surface, the higher part therefore represents a hydrostatic pressure that facilitates the infraction of the water into the hollow on one side more than on the other. We can imagine the same ld also hold good if the water were higher on one e other by any other mode of production than that ntally, 185 prop., as, for instance, if the water were d as a compression by the horizontal force of the ion of a hydrostatic pressure thus placed, upon the be found equal in its power of locomotion to a ce in moving to the most free area.

ctions given above are also displacements of a part water, therefore the velocity of the wave movement o that of the fall by *infraction*, so that these infractions e distances apart of the waves, as pendular velocities , as the following diagram may show.

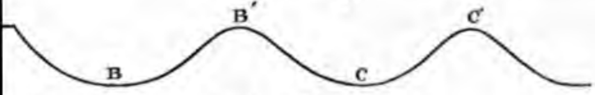


Fig. 214.—Diagram—Duplication of Infraction Waves.

g. 214, represent a surface of repose having a general above the average plane of motion, under the con- 185 prop. *g*. Let the lowest motive plane in the face be represented by B and C, in the figure. Then elevation is shown above that given for the conchoidal wave of equilibrium, 189 prop., and therefore by principles proposed there would be infractions on the wave C and upwards which would have equal oscillatory force to the infractions A to B per volume for the less volume that would flow from B to C. As these forces would oppose each other there would be some difficulty in assuming the pendular velocity of the infracted system A to B and B to B simultaneously. In this case, we find that the wave is rendered locomotive, and of such period that the constancy of pendular oscillation from A to B impressing the side B B of the wave B B C overthrows its equilibrium and renders it projectile. The progressive velocity being ruled by the pendular infractions; at the same time we have a general reflex action of the surface water, as may be shown in the diagram below.

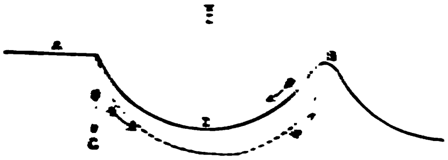


Fig. 215.—Diagram—Whirl Oscillation.

f. Let the *potential* of A, Fig. 215, by its direct gravitation impulse have a force downwards shown by the arrow G, this under resistance will produce the curve D by restraint of free gravitation and therefore resemble the action of a pendulum whose axis would be at C above the wave. This being the case, such potential force as is represented by the elevated part, having no restraint at C, as in the case of a pendulum, would have a certain gravitation momentum to enter the surface as a whirl, as shown by the dotted line to B, as before stated (188 prop. *b*). In this case it would complete so much of its impulse as may be contained in the curve, shown by the dotted line to the point B; now as B would at the same time be partially infracted at its surface towards D, the water would rise through the whirl and fall by infraction into the hollow; at the same time the entire projectile force of the whirl, derived from the potential A, would be locomotive in following the most infracted part. I think this motion may be very fairly assumed since the water to form the wave B is evidently removed from A, while the surface of the wave in this case is moving oppositely, B towards D. In such

ion, the parts of the hollow of the wave at D are
ll circles by the differences of tangential velocities

t equivalent conditions of superficial oscillation to
the present proposition § *c* are given by Newton in
44*th prop.* 2*nd book of the Principia*, which he demon-
nt tube partly filled with water in which the water
a pendular velocity equal to a free pendulum whose
hat of the water in the tube. The tube experiment
be assumed to take the place of the hollow in the
ition. Newton proposes, by inference of this experiment, that a protuberance or wave upon a liquid surface will *sink beneath* the surface of equilibrium, and rise again above it alternately upon the *same area* similarly to the oscillation in the bent tube. If this be so, it appears to me to be in no way demonstrated by his experiment which is that of a lateral movement of the kind I propose for *surface* motion. I think that as so much of wave philosophy has been built upon this proposition it may be as well to discuss the
at more in detail; for although I feel in this par-
greatest admiration for the ingenuity of our great

are all performed in equal times, whether the motion be more or less intense.[1] This principle of pendular motion carried out showed that the surface wave of the ocean would have a velocity in the sub-duplicate ratio to its breadth. Therefore that a pendulum whose length between the point of suspension and centre of oscillation is equal to the breadth of the wave, that is, of the wave from crest to crest, would perform a single oscillation in the same time that a wave would advance a space equal to its breadth. Newton notes that this would be true on the supposition that the parts of the water ascend and descend in direct lines. But really the action of ascent and descent is performed in a circle. Therefore the time proposed only nearly approaches the truth.

i. In this tube experiment there is no doubt the oscillation should be strictly pendular, the principles of the pendulum being fully involved in it; the resistance from friction and other effects being *equal* in each arm of the tube. If the same principles are applied to motions upon a hollow upon the surface of a liquid the same equality of conditions also occur; the action of gravitation being equal and the resistance equal for each oscillation on each side of the arc which forms the hollow.

j. But, if we apply the above to the direct vertical descent of the crest of a wave into resistant water beneath, the conditions are evidently different, as in this case, the raised mass which forms the wave is directly active as a hydrostatic pressure upon the body of water beneath, which is practically *incompressible* in the *vertical* direction of the pressure, whereas laterally it is nearly free to move on each side from the crest of the wave. Therefore by the nature of a hydrostatic pressure it would move the elevated water not directly *downwards*, but to the *free areas of the lateral parts*, so that the highest parts would flow into the hollow by deflection from the rigid resistance beneath; exactly as it flows in Newton's tube experiment under like deflection by the directive curvature of the tube. It appears to me we are bound to conclude that in this case by the conditions of the resistance present. For a free oscillation to move, as suggested, vertically into the surface of an incompressible liquid beneath, as Newton's theory demands, we should need a *vacant space* for it to move into, so that it might oscillate somewhat in the manner of a scale-beam in the air. Otherwise the small impulse of the falling water would move clearly only to the area

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[1] *Principia*, Book ii. Sect. viii. Props. 45, 46.

istance, which would be into the free open lateral
ropose. Further, that it does move in this manner
lly is clear to observation.

probable that the infraction of surface hollows may
essions and other causes, meet such interference as
ctly pendular velocities to the wave, but in so far as
experiment may be applied to surface motions the
e exact within the limits of frictional restraint.
s we are assured by many observers that the wave
e pendular velocities, I propose that a *pendular in-*
hollow is the ruling cause thereof.

rther one point to be observed that may appear a
ly, that by *compression* upon a surface, waves are
from the compression, whereas by this proposition
wards the infraction; that is, when the infraction is
w the general plane of surface equilibrium; so that
hich is equal to a *compression* sends waves *forward*
a falling tide which is equal to an infraction sends
ward in the same direction towards the shore, and
rence in this case in the form or direction of the wave,
mpression or infraction. This principle is fully de-
171 prop., and by this proposition; another instance

exterior force acting vertically upon the system. In this case such means, for instance, will answer our purpose as that of moving the finger up and down within the surface of a liquid.

b. This principle of motion on a liquid surface may be shown as follows:—

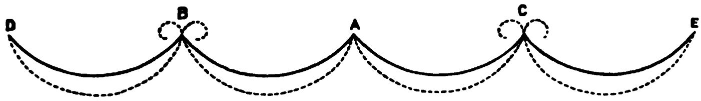


Fig. 217.—Diagram—Equal Space Oscillation.

Let an oscillatory motion be engendered and constantly maintained in a parallel channel at A, in the above Fig. 217, by constantly impressing a force to compel this point to move upwards and downwards; and let this force occupy no area that would cause a displacement of the liquid, but be as an alternating hydrostatic pressure only, as for instance, if we can imagine such, by an alternate inequality of the action of gravitation on this small area. Then the downward impression of such force would engender a biwhirl under the motive point A by every downward impression, whose whirls would be projected right and left in the parallel channel until the projection was restrained by the liquid surface at the crest of the next point formed by biwhirl action at B and C on the surface produced by deflection of the whirl. Let this complete biwhirl be shown by the dotted lines extending from A to B and A to C, and suppose the part of the dotted line, shown in the aerial space above, to be retained by the cohesion of the water; then, such whirls moving upwards to complete an oscillation would adhere to the adjacent liquid on the surface from C towards E and B towards D upon which they would make rolling contact. Therefore other like opposite whirls would be induced to rise upon the surfaces C E and B D, as shown by the dotted lines and these whirls would induce others, so that the oscillatory system of a liquid, *engendered and maintained* by the means proposed, would resemble a series of equal surface *rockers*, one rocker moving the other by contact upon it.

c. We must only take from the cases given a purely theoretical idea of a whirl-motion, as it is quite clear water could not curl as proposed in air, but the principle of motion will be established if the above be consistent with the form observable, as this would be modition acting upon it. Under the conditions assumed would fall as soon as their infraction figure permitted and the whirls themselves, from the adhesion of the project the liquid upwards to a ridge only. The ay be shown by the diagram below, Fig. 218, where of the whirl is shown theoretically by the dotted

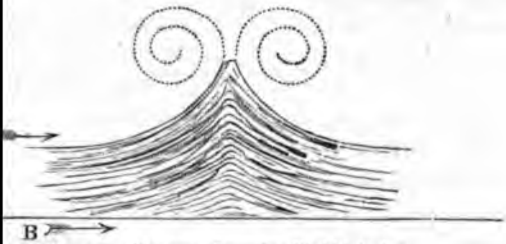


Fig. 218.—Diagram —Imperfect Biwhirl Action.

vave is actually represented beneath; the vertex of shown projected between the assumed whirls.

waves by underflow.

principle undercurrents in liquids will produce only ss of waves which may be termed ripples. On the in which the flowing forces make rolling contact upon liquid planes of greater resistance. Where a flowing undercurrent is resisted by any means, as by a less velocity or difference of direction in the surface water, the continuity of the carrying power of the undercurrent will be resisted, and the flowing water deflected from its direct course by the cohesion to the more resistant surface parts. The momentum of the flowing water by the continuity of its force will therefore deflect the surface upwards, forming whirls which give the projected parts a tendency to overflow the undercurrent.

b. The principles of the above become apparent when there is perfect resistance at the surface by a floating fixed object in a running stream. Thus, I have noticed at London Bridge and elsewhere, that a boat at anchor will quite turn the current ripples of the ebbing tide so that they will break against the flowing direction of the river and overflow in consecutive waves for many yards before the stream reaches the boat. The diagram below, Fig. 219, represents the direction of the motion somewhat exaggerated, each wave being shown curling upward from the boat.

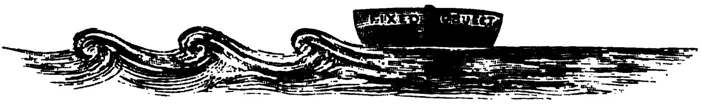


Fig. 219.—Ex.—Fixed Surface Overflow.

c. Similar waves may be observed at the back of any paddle steam-boat; the paddle giving a downward direction to the water projects it backwards, whereas the surface water follows by traction. This is shown below, Fig. 220.

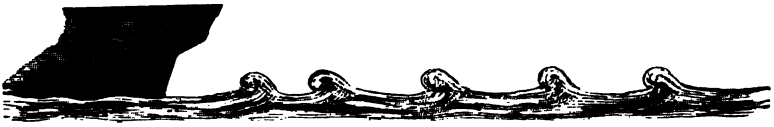


Fig. 220.—Ex.—Motive Surface Overflow.

d. In both cases the surface waves following or keeping at equal distances from the object of resistance are stationary when the resistance is fixed, or motile when it is motile. The same principle is shown by the resistance to static surface liquid in the experiment of Bossut given, 94 prop. *f.*

CHAPTER XVII.

ION OF WAVES OVER LIQUID SURFACE FROM CENTRAL DISTURBANCE.

lency of circular and parallel wave systems.

able that waves generated by central disturbances sive aqueous surface will be motive upon the same find them in parallel areas, the general conditions e discussed in the two preceding chapters. How- pagation of waves from central positions the resist- rially different. In parallel areas the impulses are lateral parts of the containing vessel, whereas in ions the resistances are circumferential, and vary which produces a wave could penetrate; so that we might expect similar effects in deep as in superficial movements.

b. In this matter the probability is that, assuming the surface to possess, as I have proposed, a certain special force of elastic extensibility, this will act so as to render it more sensitive under the influence of any distending force that throws it in one place out of level, than at a greater depth, where the equilibrium may be less sensitive, the disposition to extensibility reinforcing, as it were, a continuity of the compression. It is nevertheless clear that there is considerable elastic rigidity in an aqueous system at all depths, as evidenced in the persistency of compressile waves (172 prop.).

c. The fact of the facility of propagation upon a liquid surface of very small forces was shown, 15 art., in the pricking a liquid surface with a needle, by which a wave was shown to be propagated to the extent of the borders of the containing vessel. We may find that an equivalent motive propagation to this will be produced by forces that are greater. Thus, if instead of using a needle we intrude a larger object as that of a cone of a quarter of an inch diameter of base, this will in like manner disperse a motion from the centre, as we should conclude, but in this case the disturbed surface will be pressed more against the resistance of the elastic surface extensibility (16 prop.), and the surface will be crumpled up into not less than two protuberances and an intervening hollow. When the crumpled surface, or wavy form, is once set by the impulse, whether it produce one or more waves this form will extend to such an area of inertia that the resistance becomes in equation with the original impulse; leaving in all cases a plane of perfect repose after the wave or waves have passed over the surface. This repose is so perfect that I have found central dispersion of waves the best means of bringing a disturbed surface to rest for continuing other experiments.

195. Production of surface waves by falling drops.

a. To follow the effects of dispersion of small forces in liquids by visible waves, to which I limit my experiments, the best method that I was able to devise was by dropping water in separate drops upon a still surface. I found that by this means I could observe the effects of separate units of compression and infraction, in a manner quite within control. The waves produced in this manner extending in gentle undulation from the centre, I could also readily observe uniform effects by permitting the drops to fall at equal in-

one wave followed closely after another. Indeed
very approximately produced by carefully observing
single drop in the manner I will describe.
periments with drops falling upon a smooth liquid
aving made a few trials by dropping single drops of
circular dish, and then in a large tub, I found the
e single drop-waves could not be followed for careful
a vessel of less diameter than 12 feet, which I was
elled to construct. Having this vessel prepared I
e centre of it a simple apparatus constructed of a
ood screwed together, to which I fixed by means of
lley a glass dropping-tube at any required height,
tact to 3 feet from the surface of the water. Upon
I placed an adjustable shelf to support a tin pot,
e to supply the dropping-tube by means of a small
phon, as required.
end of the dropping-tube was now fixed at a dis-
ches above the surface of the water over the 12-feet
height of the tin pot was so adjusted as to permit
l at about every minute of time. The drops at the
ng the tube were about one-sixth of an inch dia-
y as I could measure them.

of the projection of the splash was readily seen by letting the drop fall near any small floating solids, as pieces of cork, which were instantly projected therefrom.

f. The first contact of the drop, as nearly as my powers of observation would permit, was as represented below, Fig. 221, which is enlarged about 1½ diameters, the liquid surface being shown in section.

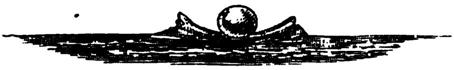


Fig. 221.—Ex.—Contact of a Drop upon a Surface of Water. (Enlarged 1½ diameters.)

g. After the percussion of the drop upon the water surface there immediately followed a recoil, in which the drop of water rebounded, carrying with it a certain quantity of the surface water which adhered to it, forming thereby a column, in height about three times the diameter of the drop. The water forming the column appears to be taken entirely from the hollow; the ridge at first formed by the percussion meanwhile continuing its movement outwards from the centre of the percussion area. This column appears when it is reflected to about two-thirds of its full height, as shown in Fig. 222, below.

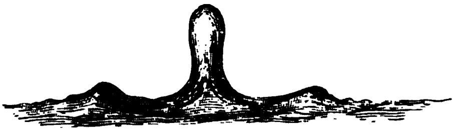


Fig. 222.—Ex.—Recoil of Drop after Contact upon Surface of Water. (Enlarged 1½ diameters.)

h. As the drop rises the remaining third above the height shown enlarged above, the cohesion of the water can no longer maintain its continuous form; at this point, therefore, a sudden contraction

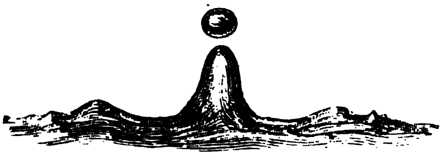
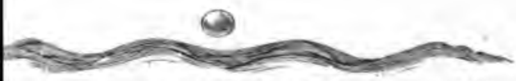


Fig. 223.—Ex.—Ejection of Drop upon Recoil from Surface of Water. (Enlarged 1½ diameters.)

occurs at a distance of about one-third from the top of the column, and the head separates in the form of a separate drop, which is jected a short distance above the parted column. t reforms beneath to the like figure the water had in shown in the sketch, last page, Fig. 223.

e whole of the short time occupied in the operation hollow upon the surface of the water around the to enlarge in circumference, and the outer ridge or ne flattened out to conchoidal form; the first ridge same time constantly outwards from the centre.

ving instant the column sinks down, and immediridge, as that of the first percussion of the drop, but be of greater volume, and takes at once a conchoidal ng the entire water of the column shown in the last . 223. The appearance, as nearly as I could observe



x.—Surface at the time of Fall of Reflex Drop. (Enlarged 1½ diameters.)

a period, by taking observation of fifty consecutive this time nearly as in the sketch above, Fig. 224.

ted drop now finally falls upon the water with very except for a small part, as I will hereafter show; its force is therefore principally developed, or continued outwardly by deflections, to a horizontal direction from the point of contact, so that we find by observation that each wave, *in this case*, is derived from a single effort of percussion, or compression upon the central liquid area.

m. We have therefore for the three principal protuberant waves shown in section in the preceding diagram, Fig. 225:—

A A′ a percussionary wave formed by the water ejected from the first percussion, at the outer edge of which there is found a series of ripplets formed by an incipient splash, which produces altogether an imperfect circumscribing wave undulatory towards its vertex, but ragged in front.

B B′, secondary reflected compressile wave, containing a hollow in front drawn up in the recoil from adhesion of the surrounding water, as shown Fig. 222, this wave from falling by natural gravitation into the surface beneath, produces a perfect wave of a low conchoidal type (187 prop.).

C′ C″, third final projectile wave, caused by the detached drop, illustrated in Fig. 223; this drop follows closely the descending nipple which forms the previous wave B B′. It is produced with much less force, and is followed by the same secondary phenomenon as the first percussion from the drop falling 5 inches, § *c*; the wave formed is therefore imperfect, being followed by a series of very small undulations, which in miniature repeat the entire phenomenon.

n. From the above we may conclude that the entire phenomenon here discussed is the result of impression of force derived from percussion and surface reflection of two material bodies, the large mass of water and the drop. In this case the wavy surface is not a matter of chance, as it were, or of oscillation, but each wave is an individual protuberance derived from a single motive cause; and we may observe also that it has a definite individual action, capable of continuity, but incapable of engendering other forms of surface-motion, or of reproduction of its own form.

o. I may here mention that there may be a cause of failure in repeating this simple experiment. Thus if the drop falling the given distance of 5 inches be too large, it will sometimes eject two or three drops from the top, that will confuse the whole phenomenon. I have found another method of dropping very satisfactory, which is to point a piece of glass and dip it in water for a given

ient water will adhere for a perfect drop to be formed.
ew trials will exactly answer in its motive effects the
re given.

e series of waves have been formed by our drop, as
5, each by its distinct generic cause, these waves ride
outward from the centre, whence the motive forces
And here it is most important to note the perfect
the water left after the waves have passed, that is
able when the final wave about C has passed only
the centre; which shows the perfect solidity of the
edom from any oscillatory motion from reaction. For
membered that it is not the water which is moving
the wave, but the impressed force acting upon the
It can be clearly observed that the water remains
ionary to the wave progression, and only moves up-
nd returns to its *original position.* Of the pendular
alanced oscillation there appears to be no trace in
enomenon.

eneral appearances we may imagine that the impulse
it were, the water into a superficial loop by its com-
that the water falls to its surface by gravitation, the
g the original force, less the potential energy in the

same three waves will occupy about 4 inches; at two feet distance about 7 inches, and at three feet about 11 inches. The overflow from the top of each wave causes the retardation of the next following, and the acceleration of the wave in front. I may note that upon the principle of the pendular theory, waves should remain at equal distances apart according to periods of oscillation. They do not do so in the case of these small waves, and my experience tells me that waves do not in any case that I have been able to carefully observe, except they be maintained by undercurrents, wind, or other force, and are restricted in area of propagation by resistance; but that in all cases, where free from restraint, they spread out and diffuse themselves over the water surface, increasing in amplitude as these minute waves do, the water running down by natural gravitation to fill the hollows, on principles of infraction already discussed.

b. The velocity of the wave has nothing to do with the distance of hollows and tops of these small waves, and there is no oscillatory period. The wave-force appears to proceed with a velocity in constant equation with the particular constitution and elasticity of the fluid affected. In my experiments with a falling drop upon a surface of water 6 inches deep, the central wave B, Fig. 225, travelled with a velocity somewhat under 9 inches per second, that is, from 8 to 9 inches, the first wave being quicker, the second slower. The method of observation followed was to have a marked rod supported lengthwise at a short distance above the water surface; the surface of the under side of the rod was white and the figures black, so that they could be seen reflected on the water surface; if the sunshine fell upon the rod a shadow was produced in the water, and up the edge of the shadow the ripple or wave could be clearly traced as it passed along the deflected reflection.

c. By careful observations on a still day, taking the mean of 20 observations of the wave B, Fig. 225, its velocity of propagation was 8·4 inches per second for a distance of 5 feet from the centre; at this distance it could still be distinctly seen. This wave B was the best defined of the series, A and C were nevertheless quite distinct at this distance. The mean velocity of A was about 9·1 inches per second; C about 7·9 inches. The extreme ripples in front of A about 9·3; the last ripple following C about 7·8 inches per second. The above dimensions are approximate; the vessel

ctly shaded, and any slight wind or draught made a
e in the velocity of propagation.

is of the projectile action of a drop falling upon whirls engendered within the lower water.

ts of projection of drops *within* water have been dis-
prop. By the conditions just proposed the larger
entire projectile force in the falling drop is active to
ce waves. The evidence of percussion and recoil
on, by which the separate waves are produced in the
ents just discussed, should, however, be made evident
e projections of whirl-rings from each impulse. This
nce of the separate geneses of waves from a falling
t necessary to investigate, as the means were at hand
apparatus. I therefore changed the water in the
before described, and filled it with water coloured
of carmine. In this experiment the first drop en-
irl-ring, but the reflex action that might be observed
urface motions, was not of sufficient energy for the
e and final drop when falling upon the surface to
rate distinct rings, without confusion from nearness.
ised the dropping-tube and the supplying vessel 30
he surface of water in the trough instead of 5 inches

of experiments, Fig. 225. From the projection being greater in this case than in the previous experiment, the nipple rises in a columnar form to about one and a half inches as shown, Fig. 226; the second ring being formed by the descent of this nipple. From the time of continuous projection of this long descending nipple it does not produce within the water a perfect ring, but a whirl-ring united to the following less percussionary matter, so that it appears as a very fine cone of colour terminating at the apex as a fine thread; the whole cone being distorted by motions already engendered in the water upon which it is projected. After the second ring a third follows from the projected reflected drop which produces the wave C′ C″, Fig. 225, of previous experiments. In this case the drop falling on a disturbed surface is much more distorted, and sometimes so confused as not to be distinguishable as a whirl-ring. But in all cases there is a third detached system of colouring matter projected, so that upon the whole, this experiment gives evidence of the three projectile impressions producing the waves previously discussed, which is my present purpose to assure. The appearance within the water is represented in the diagram below, Fig. 227.

Fig. 226.—Ex.—Nipple produced by Drop Falling 30 inches.

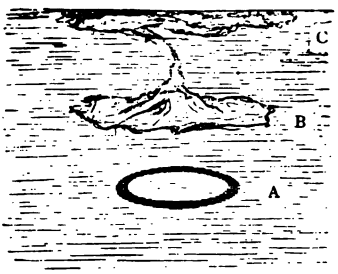


Fig. 227.—Ex.—Effects of Percussion and Repercussion in producing Whirl-rings.

A, Effect of first percussion, producing a whirl-ring.

B, Effect of descent of reflected column, after first percussion of the drop, producing an imperfect ring united by a cone.

C, Incipient ring from final drop, generally of irregular and broken form.

tion of larger waves by central forces.

e is the limit of my experiments of central forces,
esultory experiments which were followed with in-
o obtain reliable results. For larger waves we have
ents and principles offered by M. Flaugergues,
should be discussed here to fill up the defect; for,
experiments are somewhat rough, his arguments,
the appearances produced, agree very well in some
inferences that might be drawn from experiments
llowed for the propagation of direct wave motions.
that M. Flaugergues adduces from these experi-
hink, important for consideration of the subject, I
them somewhat in detail in place of experiments I
low, if convenient opportunity had permitted.

ergues commences his operations upon a smooth
nk 12 feet square and 3 feet deep filled with clear
ed in the shade protected from all winds. He then
follow the motion of each separate wave engendered
se following no preconceived idea of an oscillatory
orm of motion. In his observations he follows the
ngle wave, or small group of waves, which he pro-
ng the surface of the water with a cylinder of copper

that is raised above the level of the stagnant water. And as a part of this water flows from every other part of the surface into the hollow formed at the place of the shock, this hollow becomes more than filled, until the water rises in such a manner as to produce around it an intumescence or new wave which is propagated circularly as the first. This effect being repeated in this manner several times, the surface of the water becomes divided into a great number of concentric circles raised and lowered in succession; which has given the idea of an oscillatory movement such as has been held heretofore."

d. M. Flaugergues here identifies the individuality of the wave, and it appears somewhat curious that having done so he should not have refined his mode of production. The stick which strikes the water is withdrawn and the hollow left, the whole motions from this rough experiment being accounted for in a concrete sentence. M. Flaugergues further developes his theory, but goes little further in the direction of experimental demonstration. His final conclusion, derived from arguments and mathematical demonstrations, is that the velocity of the wave is in all cases the same, whether large or small, and is derived from the molecular mobility of the water through which it passes, and not from any principle of oscillatory motion, nor in oscillatory periods. He throws stones, large and small, into the still clear water of a river, and finds no difference in the velocity of the wave produced, although there is great difference in its dimensions, and concludes by his experiments, that the single wave of any altitude travels outwards at the velocity of 30 French feet in 21 seconds. In going roughly over M. Flaugergues' experiment upon a pond of about 50 feet diameter, of depth varying from 5 to 2 feet, I have found the velocity of the wave approximate to M. Flaugergues' measurement, and what is important, of nearly equal velocity for all sizes of stone that I dropped to generate the wave, a little greater velocity only being observed from larger masses after deducting the mass radius.

e. Mr. J. Scott Russell, to whose work I have often referred, has given 8½ inches per second as the velocity of small surface waves that he terms capillary waves. M. Flaugergues gives 18 inches nearly, but the circumstances of production are very different. In all cases I have found that the separate waves of a group have a varying velocity by their constant separation (187 prop.), therefore no

an be found, although the mobility of a liquid surface
velocity to be approximately equal for very small

ears to me in the above experiments of M. Flau-
ng analogy to the principles shown in my drop ex-
n in this chapter, in the reflex action observable in
s. But in the striking a surface with a heavy body,
ction of stones, we have clearly complicated pheno-
from the *splash* which would be difficult to follow,
results.

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